



*Developing and Adopting Complex Health Innovations –
The Case of Genetically Modified Mosquitoes for
Malaria Eradication*

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Declaration of originality

I herewith declare that the material presented in this thesis for the degree of Doctor of Philosophy is my own original work undertaken under the supervision of Professor Andrea Crisanti, Professor James Barlow, and Professor Rifat Atun at Imperial College London. Parts excepted have been duly acknowledged and appropriately referenced.

Valentina Cisnetto

December 2016

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Abstract

Background: Malaria, a preventable and curable disease, is still one the primary causes of death worldwide. Around 90% of deaths occur in sub-Saharan Africa. Increased funding and new programmes by international agencies and national governments have led to significant progress in malaria control, but the improvement curve is levelling off. This is due to the limitations of current technologies and difficulties in deploying the interventions on the ground. There are calls for technological innovations which are able to provide interventions that are cost-effective, sustainable, area-wide and equitable. The development of self-sustaining genetically modified (GM) *Anopheles* mosquitoes is deemed to have these potential attributes, but this technology is not only innovative, but also highly complex and controversial. Using the introduction of GM mosquitoes for malaria eradication in Burkina Faso as an example this study helps to better understand how complex health technology innovations are adopted in low-income countries.

Methods: The research uses a mixed methods approach and combines an in-depth analysis of the Burkinabé (Burkina Faso) health system and its wider context, qualitative system dynamics modelling and an econometric analysis in order to investigate the key barriers and enablers that influence the adoption of GM mosquito technology.

Results: The research confirms the importance of community trust and acceptance, and health system readiness, in influencing the adoption process. It also emphasises the need for a perspective on the adoption of highly complex innovations which takes more account of the iterative nature of their development, the interrelationship between development and adoption, and the cognitive barriers in stakeholders' understanding of the technology.

Conclusions: The intrinsic complexity of the technology development and local adoption processes, and the fact that the nature of the technology itself means that adoption decisions are societal rather than individual, together have important implications for policy and practice. These need to be taken into consideration both by local policy makers and technology researchers.

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List of abbreviations

ABNE	African Biosafety Network of Expertise
ACTs	Artemisinin-based Combination Therapies
AIDS	Acquired Immunodeficiency Syndrome
AMU	Assurance Maladie Universelle
ANB	Agence Nationale de Biosécurité
ANC	Antenatal Care Centres
CAMEG	Centrale d'Achat de Médicaments Essentiels Génériques et des Consommables Médicaux
CDC	Centers for Disease Control
CEDIM	Centre de Documentation de d'Information sur le Médicament
CHMP	Committee for Medicinal Products for Human Use
CHN	Centre Hospitalier National
CHR	Centres Hospitaliers Régional
CHU	Centres Hospitaliers Universitaires
CHW	Community Health Worker
CIA	Central Intelligence Agency
CM	Centre Muraz
CM	Centres Médicaux
CMA	Centres Médical avec Antenne Chirurgicale
CMLS	Comité Ministériel de Lutte contre le SIDA
CNAOB	Centre National d'Appareillage Orthopédique du Burkina
CNBE	Comité National de Bioéthique
CNLAT	Centre national de Lutte Antituberculeux
CNRFP	Centre National de Recherche et de Formation sur le Paludisme
CNS	Conseil National de Santé
CNSS	Services de Santé de la Caisse Nationale de Sécurité Sociale
CNTS	Centre National de Transfusion Sanguine
CRSN	Centre de Recherche en Santé de Nouna
CSNB	Comité Scientifique National de Biosécurité
CSPS	Centres de Santé et de Promotion Sociale
CT	Conseiller Technique

CVD	Conseil Villageois de Développement
DAD	Direction des Archives et de la Documentation
DAF	Direction de l'Administration et des Finances
DAH	Development Assistance for Health
DCPM	Direction de la Communication et de la Presse Ministérielle
DCPP	Direction de la Coordination des projets et programmes
DDT	Dichloro-Diphenyl-Trichloroethane
DES	Direction des Etablissements de Santé
DFP	Direction de la Formulation des Politiques
DGESS	Direction Générale des Etudes et des Statistiques Sectorielles
DGMPL	Direction Générale de la Pharmacie, du Médicament et des Laboratoires
DGS	Direction Générale de la Santé
DHS	Demographic and Health Surveys (USAID)
DL	Direction des Laboratoires
DLM	Direction de la Lutte contre la Maladie
DMP	Direction des Marchés Publics
DMPT	Direction de la Promotion de la Médecine et de la Pharmacopée Traditionnelles
DN	Direction de la Nutrition
DNA	Desoxyribonucleic Acid
DOT	Directly Observed Treatment
DPPO	Direction de la Prospective et de la Planification Opérationnelle
DPS	Direction de la Promotion de la Santé
DPV	Direction de la Prévention par les Vaccinations
DRH	Direction des Ressources Humaines
DRLP	Direction de la Réglementation et des Licences Pharmaceutiques
DRS	Direction Régional de la Santé
DS	District sanitaire
DSAP	Direction de la Sécurisation des Approvisionnements Pharmaceutiques
DSEC	Direction du Suivi, de l'Evaluation et de la Capitalisation
DSF	Direction de la Santé de la Famille
DSITS	Direction des Services Informatiques et de la Télésanté

DSS	Direction des Statistiques Sectorielles
ECOWAS	Economic Community of West African States
ENSP	Ecole Nationale de Santé Publique
EPA	US Environmental Protection Agency
FDA	Food and Drug Administration
FNIH	Foundation for the National Institutes of Health
GDP	Gross Domestic Product
GM	Genetically Modified
GMM	Genetically Modified Mosquito
GMO	Genetically Modified Organism
GNI	Gross National Income
GNLC	Centre National de Lutte Contre la Cécité
HEG	Homing Endonuclease Gene
HIV	Human Immunodeficiency Virus Infection
ICREC	Imperial College Research Ethics Committee
ICT	Information and Communication Technology
IMF	International Monetary Fund
IPT	Intermittent Preventative Treatments
IPTp	Intermittent Preventive Treatment of Pregnant Women for Malaria
IRS	Indoor Residual Spraying
IRSS	Institut de Recherche en Sciences de la Santé
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ITNs	Insecticide-Treated Nets
ITSS	Inspection Technique des Services de Santé
LDCs	Least Developed Countries
LLINs	Long-Lasting Insecticidal Nets
LNSP	Laboratoire National de Santé Publique
MCD	Médecin-chef de district
MDGs	Millennium Development Goals
MEF	Ministère de l'Economie et des Finances
MIS	Malaria Indicator Survey
MPP	Mouvement du peuple pour le progress

MRTC	Malaria Research and Training Center
NFL	NetsforLife
NHS	National Health Service
NGO	Non-Governmental Organisation
NPD	New Product Development
ONB	Observatoire National de Biosécurité
OST	Office de Santé des Travailleurs
PHC	Primary Healthcare
PNDES	Plan National du Développement Économique et Social
PNDS	Plan National de Développement Sanitaire
PNLP	Programme National de Lutte Contre le Paludisme
PNS	Politique Nationale de Santé
R&D	Research & Development
RDT	Rapid Diagnostic Test
SCC	Service Central du Courier
SDA	Service de la Documentation et des Archives
SDGs	Sustainable Development Goals
SIT	Sterile Insect Technique
SP	Secrétariat Particulier ou Permanent
SP/CNS	Secrétariat Permanent du Conseil National de Santé
SSA	Services de Santé des Armées
SWOT Analysis	Strengths, Weaknesses, Opportunities, Threats Analysis
THP	Traditional Health Practitioners
UA	African Union
UHC	Universal Health Coverage
UN	United Nations
UNPCB	Union Nationale des Producteurs de Coton du Burkina
USAID	U.S. Agency for International Development
USD	US Dollar
UVRI	Uganda Virus Research Institute
VAD	Vitamin A Deficiency
VCTR	Vector-Based Transmission of Control: Discovery Research
WaSH	Water, Sanitation, and Hygiene

WHO	World Health Organisation
WHO ERC	World Health Organization Research Ethics Review Committee

1 Introduction

Over the past decade, Universal Health Coverage (UHC) has become one of the major agenda items for international agencies, including the United Nations (UN) and the World Health Organisation (WHO) (UN General Assembly, 2012). It is a priority for many national governments, especially for those from low- and middle-income countries. Enormous efforts have been undertaken to achieve UHC and it has become increasingly clear that tackling this complex challenge requires effort on all the social and economic determinants of health.

While there have been significant achievements, the goal of UHC is still far from being accomplished, despite a large number of innovative projects and programmes being implemented on the ground. Many of these innovative initiatives suffer from a wide range of problems (e.g. technology not designed to work in specific conditions, cultural barriers and population scepticism) and their adoption and diffusion is often slow and patchy (Bloom and Ainsworth, 2011).

The complexity of deploying innovations for the improvement of health, especially in low-income countries, is widely acknowledged and regarded as a continuing problem by global health organisations (Bloom and Ainsworth, 2011). Many factors are involved, not least the complex nature of health systems themselves. Challenges often increase where innovations involve novel technologies, the subject of this thesis. It is therefore crucial to understand the underlying dynamics and processes which influence the implementation and scaling up of innovative health technologies. It is thus necessary to take into consideration the multiple interactions between all the parts of the adopting system over time (Atun et al., 2007, Atun and Sheridan, 2007). A comprehensive framework, which embraces systems thinking, is therefore necessary to elucidate the complex institutional and organisational structures within health systems, and the way these shape the dynamics of adoption and diffusion within local contexts. Such an approach is essential for the efficient development and implementation of healthcare programmes that have a lasting impact on the ground (Bloom and Ainsworth, 2011, Atun et al., 2010a, Atun et al., 2010b).

These principles are applicable to the global fight against malaria (Pigott et al., 2012, Adeyi and Atun, 2010). Eradicating malaria is one of the UN Sustainable Development Goals (SDGs) – goal 3.3 reads:

*‘By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.’
(UN General Assembly, 2015).*

Over the past decade, international funding for prevention, control and elimination of infectious diseases, with a particular focus on malaria, has risen steeply from less than USD 100 million in 2000 (WHO, 2012b) to approximately USD 960 million in 2005 and roughly USD 2.5 billion in 2014 (WHO, 2015b). This has led to reinforced disease control and visible results on the ground. Between 2000 and 2015 the number of malaria-caused fatalities has decreased by 66% amongst all age groups, and by 71% amongst children under five (WHO, 2015b). Key technologies driving this decrease were artemisinin-based combination therapies and insecticide-treated bednets (Murray et al., 2012, WHO, 2015b). Nevertheless, despite increased efforts by governments of disease-endemic countries, donors and global malaria partners, the improvement curve is levelling off and millions of people continue to lack access to preventive therapies, diagnostic testing and quality-assured treatment (WHO, 2015b). In fact, the WHO estimated that as well as the USD 2.3 billion available on average every year between 2011 and 2020, approximately an additional USD 4 billion a year would be needed to achieve universal access to malaria interventions by 2020, with a further USD 3 billion required annually by 2030 (WHO, 2015b).

In the case of malaria, in addition to the difficulties in deploying the interventions on the ground, the current technologies themselves have proven to have a number of limitations, including insecticide resistance, resistance of the parasite to medications (Takken and Knols, 2009) as well as human misuse. These limitations have placed the need for a new innovative technology in order to provide sustainable, area-wide, equitable, and low-cost protection to malaria.

Target Malaria is an example of collaborative project developing this type of innovative technology. Founded in 2005, Target Malaria is a not-for-profit research consortium with the vision to eradicate malaria through the development of a

unique, innovative technology for vector control (Target Malaria, 2016c). This technology uses genetic modifications of the few specific strains of the *Anopheles* mosquito that transmit the disease, with the goal of suppressing their ability to reproduce (Burt, 2003, Burt and Koufopanou, 2004). The aim of the project is to create a strain of modified malaria mosquitoes that can pass these modified genes on to a disproportionately high percentage of their offspring; thus, the modification spreads throughout the specific population relatively quickly and is effectively 'self-sustaining'. The release of these mosquitoes would lead to a progressive reduction in the numbers of native mosquitoes able to carry and transmit malaria over successive generations until there are too few remaining to sustain transmission of the disease (Burt, 2003, Burt and Koufopanou, 2004). Hence, if successful, the number of malaria transmitting mosquitoes will be gradually reduced within large regions, thus hopefully eliminating malaria in that specific region over time. Along with other malaria elimination tools, the GM technology from Target Malaria could be a key tool for global eradication. Moreover, the resulting technology will have the potential to provide area-wide, sustainable, equitable, and low-cost protection, notably in areas where disease transmission levels are high and current control methods are not expected to be adequate to achieve malaria eradication (Target Malaria, 2016c).

The overall aim of this PhD study is to investigate the factors influencing the adoption of a complex, novel health technology in a low-income country. There are a number of studies exploring the adoption and diffusion of health innovations in low-income countries, including those relating to malaria eradication. However, technology innovations which involve scientifically cutting-edge technologies, such as GM, have not been investigated extensively. These innovations often involve a *development process* which is simultaneously embedded within the *adoption process* – iterations of the technology are trialled to validate the science, ensure the prototype technology works and safety considerations are addressed, and then the economic or practical factors are identified and tackled. Further, such technologies are intrinsically complex due to both the need to engage a wide range of health

system and other stakeholders and possible challenges in explaining the science and technology to them.

Because of its complex and controversial nature (as a genetic modification (GM) technology), as well as its lengthy and complicated development process, the Target Malaria project and its activities in Burkina Faso represented an ideal case. Using this case and a mixed methods approach, the author investigated whether lessons from extant research on the adoption of health innovations in developed and lower income countries are applicable in the case of a novel, complex, and controversial technology.

The first step of this PhD study was to gain an in-depth understanding of the existing research literature in the field of adoption of innovation in general, in healthcare specifically and finally in healthcare in low income countries. The results of this secondary research are presented in Chapter 2 and were used as a baseline to refine the primary and secondary research questions (Chapter 3), as well as the research strategy and the of data analysis tools (Chapter 4). The review of the introduction of technological innovations in health systems was then expanded with a systematic literature review of existing research on the enablers and barriers to the adoption of the major malaria and GM innovations (Chapter 5).

Given the complex nature of Target Malaria's technology (GM mosquitoes), it was essential to gain a deep understanding of every aspect of the project. This comprised thoroughly understanding the details of the technology, its development stages, and the planned timelines for every aspect of the project. These include the research and resource planning for product development, capacity building in the selected African countries, regulatory pathways, risk assessment and management, communications strategies, and stakeholder engagement processes. The progress of these work streams was carefully followed throughout the PhD study with the author assuming a part time role as associate project manager in the consortium. Gaining this deep insight was essential, given the fast pace at which the project was moving forward. Chapter 6 gives an overview of the most important findings related to the development of the technology.

Because of the way the planned development stages the Target Malaria project evolved and were subsequently modified over time, it was not possible to investigate the actual deployment of the GM mosquitoes in the field, as originally hoped. Nevertheless, by actively participating in the Target Malaria project management process and monitoring its progress, and combining this with in-depth fieldwork in the field sites in Burkina Faso, it was possible to gain deep, unique insights into the evolving and intertwined development and adoption processes. This allowed the author to explore the barriers and enablers, both uncovered by the research and predicted by stakeholders, during various stages of the adoption of Target Malaria's technology in Burkina Faso.

An in-depth analysis of the Burkinabé health system, as well as the wider national context in which it is embedded, was carried out and is outlined in Chapter 7. The study draws on a framework for the analysis of health systems developed by Atun et al. (Atun et al., 2013), which takes a systems approach (Atun, 2012, Swanson et al., 2012). This enabled the author to gain a profound understanding of the socio-economic, cultural and geographical landscape in which Target Malaria's technology is being deployed. The analysis also allowed the creation of a context-appropriate topic guide for the interviews and focus groups.

To obtain a comprehensive analysis of the key factors influencing the adoption of *other* malaria technologies within the *same* context and health system, an econometric analysis was performed examining the socio-demographic factors which potentially influence the adoption of previous malaria prevention innovations in Burkina, using data from the USAID Demographic and Health Surveys (DHS) Program. These findings are described in Chapter 8. Past malaria prevention innovations essentially involve *private goods*, i.e. those in which decisions about adoption are made by individuals according to factors such as cost, availability, and perceived efficacy. This provided useful data from which to compare factors influencing adoption decisions concerning *public goods*, i.e. where adoption decisions are not directly made by individual members of the population but by other authorities for the benefit of all, such as GM mosquitoes. While public goods do not involve direct individual choice about adoption, understanding and

acceptance of the innovation by the population in question is nevertheless a potential influence on their adoption, hence it is important to understand how the Burkina population responded to previous malaria prevention and eradication innovations. This approach therefore made it possible to expand on ex-post quantitative data on the socio-demographic factors influencing previous malaria programmes in Burkina Faso, which was then triangulated with the qualitative results from the case study analysis.

Chapter 9 elucidates the main findings from the case study. It systematically describes the key factors and dynamics influencing the development and implementation of the Target Malaria GM technology within Burkina Faso. Building on the findings from the literature reviews, the framework for the analysis of adoption of complex innovations in health systems, and the econometric analysis of factors influencing past malaria interventions in Burkina Faso, a series of interviews and focus groups with key stakeholders was performed. These ranged from policy and regulatory bodies to local villages in the Target Malaria field sites. A mixed analytical strategy based on systems thinking (Atun, 2012, Atun et al., 2010a, Atun et al., 2010b) and qualitative system dynamics modelling (Sterman, 2000, Dattée and Barlow, 2017) was adopted to analyse the data, resulting in a qualitative system dynamics model explaining the interactions in the adoption system for GM mosquitoes.

The discussion and concluding remarks in Chapter 10 summarize the key findings from this study and their implications for the body of research on the adoption of complex health innovations. Based on the conclusions, a set of recommendations for the adoption of Target Malaria's technology in Burkina Faso was also developed. These recommendations will help the project team in executing the required steps towards adoption and diffusion of the technology in sub-Saharan Africa. Finally, future research steps are identified.

2 Technological innovation in healthcare – A review

One of the first steps of the chosen research design (Eisenhardt, 1989) was to gain an understanding of the prior research on the adoption of innovation in general, in healthcare specifically, and finally in healthcare in low income countries, in order to gain a deeper understanding of the relevant theory on the matter. Given the author's limited research experience in the domain, this review was started early on in the research process so that the relevant theory and empirical research could be used to guide the research questions of the thesis and find an appropriate framework for the empirical analysis. In addition to the review of healthcare innovation adoption, a literature review of interventions in malaria control and eradication was also conducted.

Over the course of the 2000s, there have been several systematic literature reviews on the body of research on the adoption of innovations in health systems. Since a further systematic review would not have added significantly to this body of work or this PhD study, the author focused on examining the existing systematic reviews themselves. Initially, the reviews of Greenhalgh et al. (2004a), Greenhalgh et al. (2004b), Rye and Kimberly (2007), and Fleuren et al. (2004) were studied. Important studies identified in these reviews were followed-up. The reviewed research literature was discussed several times with the supervisors and other experts from the Imperial College Business School. As a result, there was continuous review of relevant studies throughout the PhD study, along with some teaching material from the health management department at Imperial College Business School.

This chapter presents the main aspects of the research on adoption of technological innovation by health systems. Firstly, the author outlines both the structure and general dynamics of health systems, as well as the nature of health technologies. The following sections examine innovation processes in health technologies, as well as adoption and diffusion aspects of the innovation process. The author then draws conclusions on lessons for the scaling up of health interventions in low-income countries.

Subsequently, and complementing the findings from the reviews on the adoption of healthcare innovation, a systematic review was conducted on malaria eradication technologies and GM innovation. Findings from this review are presented in Chapter 5.

2.1 Adoption, diffusion and scaling up of health technologies

Healthcare is often considered to be the most complex and fast-changing sector in any modern economy. The primary science base is ever-evolving and new technologies are continuously being introduced to support new healthcare practices. Nevertheless, governments around the world are concerned with the question of how to provide high quality, yet affordable, healthcare for their populations, as new technologies may increase costs in the short term and their introduction into health systems is often complicated.

In order to understand how innovative technologies can be introduced, diffused, and scaled-up in the healthcare sector, it is essential to define and discuss a number of key topics:

- Structure and general dynamics of health systems;
- Nature of health technologies;
- Innovation processes in health technologies;
- Adoption and diffusion within the innovation process in health technologies;
- Scaling up of health interventions in low-income countries.

From an understanding of these topics, the author can then develop a framework through which to analyse the adoption of innovative health interventions and apply this to the specific case of malaria eradication technology in resource-poor, disease endemic countries.

2.1.1 Health systems: structure and dynamics

In order to contextualise how to implement, embed and sustain technologies and innovations in the healthcare sector, it is important to develop a sound understanding of the general structure and dynamics of the underlying health systems. This is especially important since characteristics from other industries do not necessarily apply to the healthcare sector.

Health systems are essential for improving people's health by addressing the burden of disease and ill health due to communicable and non-communicable diseases (Atun, 2012). Additionally, they play a key role in the response to public health crises and indirectly contribute to economic growth and increased wealth by reducing the burden of poor health, one of the major constraints on economic growth (McKee et al., 2009). Given their nature and role, health systems are considered extremely valuable by society and it is crucial to understand their specific characteristics in detail.

A health system cannot be considered a conventional market because its interactions, structure and the arrangement of the whole system differ substantially from typical consumer-led markets (McGuire et al., 1988c, McGuire et al., 1988f). Health systems display most of the attributes of complex systems, notably many interdependent constituent parts with intricate relationships between them, feedback and emergent behaviour (Plsek and Greenhalgh, 2001, Plsek and Wilson, 2001). Due to this multi-layered nature and the large number of stakeholders involved, health systems are inherently complex. Thus, describing their characteristics is challenging (McGuire et al., 1988c). Equally, it is demanding for those stakeholders responsible for planning and managing health systems to obtain reliable information from which to make the informed decisions essential for change management and innovation.

Healthcare is not a conventional commodity (McGuire et al., 1988e) due to its complex nature, the fact that the consumer is not dealing with a homogeneous set of products and the intrinsic value that society attributes to it (McGuire et al., 1988e). Therefore, the consumer (patient) cannot value the product autonomously, especially since detailed knowledge of specific information and data is required to

understand it (McGuire et al., 1988b). The consumer has no direct access to the commodities or services, but is channelled through intermediary bodies: healthcare providers and health practitioners (McGuire et al., 1988f). Furthermore, the intermediary body has no direct link to the producer due to regulations established by bureaucratic structures (McGuire et al., 1988f). This particular distance between the consumer (demand) and the producer (supply) differs in each health system, as it is strongly dependent on the number of bodies present.

In addition, regulation in the health system has grown substantially in recent decades, making healthcare arguably the most *heavily regulated* sector in the world. This is driven by the ambition to limit potential risks to patients, as well as to guarantee efficacy and fair use of the products and services. This is enhanced by the value that society gives to these innovations, their demand, and by the problem that governments face in terms of cost and equity of healthcare (McGuire et al., 1988d, McGuire et al., 1988a).

Each health system has a *variety of interdependent stakeholders* such as provider and financing organisations, professional groups, supply chains, patients, and politicians. These stakeholders create an intricate network of relationships and entrenched cultures. Most health systems comprise a mix of public and private bodies, with interacting and parallel responsibilities, thus adding another layer of complexity (de Savigny and Adam, 2009). Especially in resource challenged settings – in countries where demand for safe and reliable healthcare widely exceeds the corresponding supply – the boundaries between public and private healthcare roles and functions have often become blurred (Bloom and Ainsworth, 2011). This has led to pluralistic health systems, with increased involvement of providers of goods and services working outside of the regulatory framework (Bloom et al., 2008) (Bloom and Ainsworth, 2011).

Health systems are also characterised by *complex funding mechanisms* focusing on different activities and different groups. In high-income countries, these are under pressure due to escalating costs due arising from growing demand. By 2014, the USA was spending 17.1% of its GDP on healthcare (World Bank, 2016b) and the UK 9.1% (World Bank, 2016b), with the NHS being the largest employer in the country with

over 1.3 million staff (Grosios et al., 2010). In contrast, low-income countries face resource constraints, leading to problems concerning equity and affordable healthcare. In 2014, Burkina Faso only spent 5.0% of its GDP on healthcare; Kenya and Mali are largely in line with healthcare spending of 5.7% and 6.9% respectively (World Bank, 2016b).

All these characteristics lead to strong intrinsic complexity, and, as will be shown in the next sections, have implications on the complex paths for the deployment of innovation in this sector.

2.1.2 Health technologies

The term ‘technology’ is very interlinked with discussions about ‘innovation’. Since both terms are not always used coherently and sometimes even synonymously, it is important to differentiate and define them. The term ‘technology’ generally refers to the application of science and engineering to create useful *physical artefacts* or to solve problems. It therefore refers to the knowledge embedded in a material product or non-material process or service. As a verb, ‘innovation’ (see Section 2.1.3) tends to refer to the *processes* involved in creating new material products or non-material processes, services or organizational forms, from initial invention to adoption and diffusion. The term is also used as a noun to refer to something that is novel or new (Barlow, 2017).

Hard and soft technologies

A distinction needs to be made between hard and soft technologies. *Hard technologies* are tangible assets such as computers, phones, but also devices and equipment used in healthcare (Mitcham, 1994, Swamidass and Nair, 2004). *Soft technologies* comprise the knowledge about those assets like manufacturing techniques and know-how with total quality management and statistical quality control being examples for the latter (Mitcham, 1994, Swamidass and Nair, 2004).

In common understanding, technology is often associated with complex devices or machines. Especially in the healthcare domain, this association proves to be too narrow since a lot of innovation occurs in soft and know-how-related technologies (Hersh, 2009). Furthermore, in the healthcare sector, soft technologies are frequently only seen as an enabler of process standardisation and communication between providers (Hersh, 2009). This is also an incomplete view of the subject since soft technologies also comprise other key elements associated with healthcare innovation, such as new service delivery models or organisational changes.

Health technologies vs. technologies for health

A distinction can be made between *health technologies* and *technologies for health* (Howitt et al., 2012) (see Figure 1).

Health technologies are technologies directly designed and applied to overcome health needs and are precisely intended to prevent, diagnose or treat illness. These can range from new drugs, diagnostics, ideas, practices, tools and institutional arrangements to policies and processes (Atun, 2012). Innovations in the health sector can therefore be either very specific (e.g. a vaccine for a particular disease), more broadly applicable (e.g. a blood pressure monitor), or less tangible (e.g. clinical guidelines and electronic applications) (Howitt et al., 2012). The WHO defines health technology as “devices, drugs, medical, and surgical procedures—and the knowledge associated with these—used in the prevention, diagnosis and treatment of disease as well as in rehabilitation, and the organizational and supportive systems within which care is provided”(Kwankem et al., 2001).

Howitt et al. cluster health technologies into six categories:

- Drugs;
- Biological products (including vaccines and cellular therapies);
- Medical devices;
- Medical and surgical procedures;
- Support systems (e.g. drug formularies and clinical laboratories);
- Organisational systems (e.g. clinical pathways).

Technologies for health, in contrast, are those technologies designed for other sectors which are indirectly involved in the improvement of health (e.g. bioengineered foods and sanitation). At the boundary between healthcare technology and technologies for health, Howitt et al. place information and communication technology (ICT) (e.g. mobile phones and radio), which both directly help to provide healthcare and public health services and also generally enhance a country's economic development and the income of its population. These ICTs have a special influence achieving the MDG 8, sub-target F, enabling the benefits of new technologies, especially information and communications, in low-income countries (Howitt et al., 2012).

In the last century, the quality and quantity of technologies for healthcare have grown immensely despite the difficulties (e.g. lack of resources) encountered during the translation from clinical research into applied clinical practice products (Szczerba and Huesch, 2012). Many of these technologies, however, face difficulties in their deployment, both in higher and lower income countries. This is often due to the challenges of deploying innovations in the healthcare sector, described in Section 2.1.3.

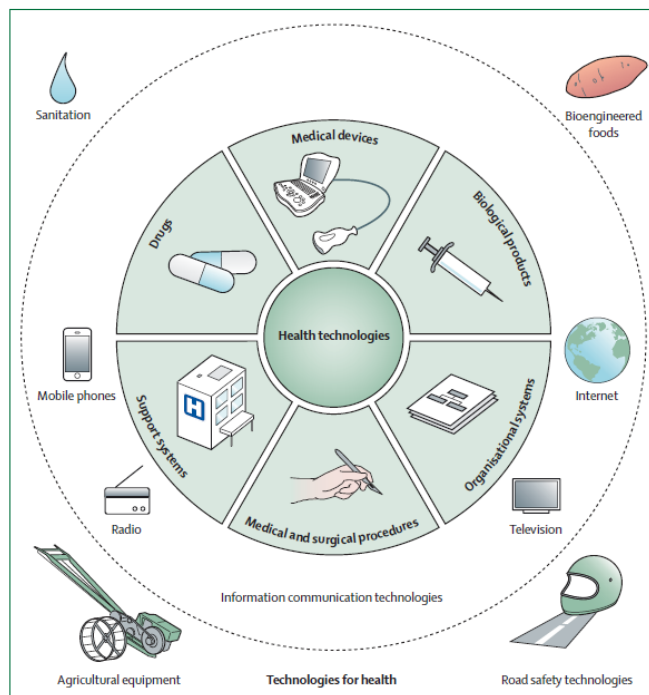


Figure 1: Overview of technology for global health.

Source: Howitt et al. (2012)

2.1.3 Innovation in health technologies

As with the case of ‘technology’, ‘innovation’ is often implicitly related to new physical objects, but it can equally be applied to new processes, services or business models. Innovation is not just the creative act or process of delivering a new product, method or idea (invention process), but also comprises a commercial or practical dimension, i.e. the successful exploitation of an invention (Rogers, 1998).

Given that this very broad definition of innovation can imply a whole spectrum of changes, ranging from the modification of an individual product component to the variation of whole systems of products and services, researchers have put forward different ways to categorise innovation.

One approach is to categorise innovation by the *type of application*: new products, new services, and new processes. Another is the *degree of novelty* to a market or to a company operating in the market (Cooper, 2001). In the first case, the innovation is completely new to a market (or country), although it does not necessarily need to be completely new in itself. For example, a company might develop an old product to reposition it in an emerging market, thus creating a product that is new to the given market (or country). In the second case, a product is new only to the company, requiring the use of new internal resources to develop it. It is possible, however, to argue that only those products or services which are new to both, the company and the market, should be considered innovative.

Another well-known approach to categorise innovation is the model by Henderson and Clark. They look at the *degree of ‘innovativeness’* by considering the amount and type of knowledge needed for the innovation to take place (Henderson and Clark, 1990). The knowledge type is divided into two constituent parts. ‘Component knowledge’ is the knowledge about the individual components that perform a well-defined function within a broader system, while ‘architectural’ or ‘system knowledge’ is the way components are integrated to enable the product to function. Their model classifies innovation along these two dimensions, with radical and incremental innovation being the extreme points along those dimensions. A radical innovation establishes a new overriding design and includes a set of core design concepts embodied in components that are linked together in a new architecture.

Incremental innovation, on the contrary, refines and extends an established design. Improvement occurs in individual components, but the primary core design concepts as well as the links between them remain unchanged (see Figure 2)

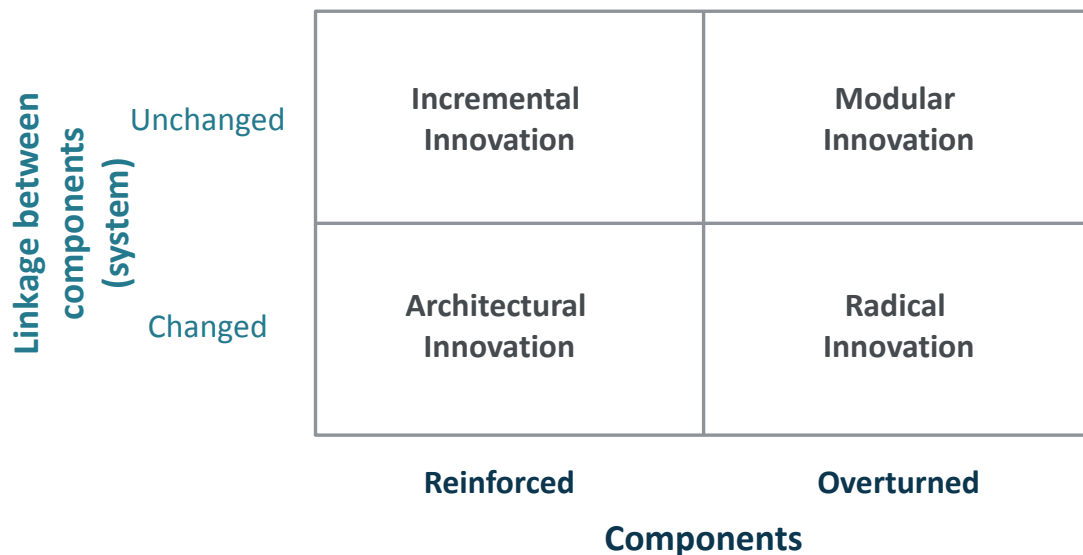


Figure 2: Four types of innovation.

Based on: Henderson and Clark (1990)

Hard and soft healthcare technologies are usually not discrete, unrelated artefacts; on the contrary, they come together as part of a technology system – the knowledge about how to operate a new medical device (the soft technology) is inextricable from the device itself (the hard technology). This attribute, along with the fact that products and services for healthcare are delivered in wider complex health systems (described in Section 2.1.3), leads to very complex innovation processes in healthcare. Therefore, conventional lessons about how innovation takes place in other industries do not necessarily apply to the healthcare industry.

Simmons et al. define innovation in the healthcare sector as "a package of interventions, rather than a single intervention, including not only new service components but also the managerial processes necessary for successful implementation" (Simmons et al., 2007). For example, programmes to enhance access to health services can be viewed as organisational innovations while the

endeavour to bring these programmes to scale can be understood as the diffusion of these innovations (Gardner et al., 2007).

The introduction of new innovative technologies in a health system sets up a series of challenges for their adoption. Addressing these challenges requires a framework that allows for a better understanding of the factors influencing the emergence, adoption and spread of innovation, and the linkages between them (Atun, 2012, Atun et al., 2010a, Mangham and Hanson, 2010, Bloom and Ainsworth, 2011). These factors include (Damschroder et al., 2009, Greenhalgh et al., 2004b): characteristics of the innovation itself, the extent to which the technology and new approaches can be tailored to the local settings, the characteristics of the delivery organisations, the broad context in which the technology is delivered and the delivering organisations operate, as well as the capacity of relevant stakeholders to implement changes.

In fact, for innovation to have a significant impact, entire system in which it is being introduced might need to be optimised, meaning that a large number of coordinated changes to multiple components of the system need to be performed at once (Szczerba and Huesch, 2012). This can be highly challenging in health systems because of their complexity, one reason why the implementation and scaling up of technological and organisational innovations can be slow and patchy (Bloom and Ainsworth, 2011). Understanding the health system – its structure and interdependencies – is therefore necessary if an innovation is to be introduced.

Even though innovation is one of the major drivers in healthcare, therefore, the response to innovation in the health system is very different from that of other markets with a strong innovative drive (e.g. mobile technology industry) (McGuire et al., 1988c).

2.1.4 Adoption and diffusion of innovation in healthcare

The economist Joseph Schumpeter divided the innovation process in three stages, often known as '*the Schumpeterian trilogy*' (Schumpeter, 1934):

- Invention – The period in which ideas are turned into workable inventions. This is often characterised either by technical development or proof-of-concept experimentation.
- Commercialisation – The period in which the potential of an innovation is transformed into economic value. In this period, the latent value of a technology is unlocked in order to generate real value. Sometimes this is now described in terms of business model creation, with business models described as enablers that allow inventors to profit from their ideas (Chesbrough, 2006).
- Diffusion – The period in which innovations are taken up and spread through a population. This process is very variable and can be influenced by many factors.

The *invention* and *commercialisation* phases have been described in more detail in the literature on new product development (Tidd and Bessant, 2014). This focuses on the processes involved over the lifetime of a development project for a new innovation, whereby researchers and companies iteratively tackle the R&D challenges, progressing from initial research, through technology development and prototyping to further refinement and eventual launch onto the market. Companies sometimes adopt a 'stage-gate' development model, with clear stages and agreed rules for proceeding or abandoning an innovation project (Cooper, 2001).

The Schumpeterian trilogy has often been criticised for being too linear and not taking the complexity of interactions amongst stakeholders and feedback between different innovation stages sufficiently into consideration (Van de Ven et al., 1999). Innovation as a process, including its adoption and diffusion, should therefore be characterised as a non-linear, dynamic system.

Nevertheless, there is a large volume of research on the *factors* which influence the adoption and diffusion of innovations, both in healthcare and more broadly within other sectors. *Adoption* can be defined as the process influencing the decision to take up a new technology or innovation, a step before the diffusion, which, as mentioned before, is the spread of the technology or innovation through a population. The *diffusion* of innovation has been extensively researched, with perhaps the most influential theory being that of Everett Rogers (Rogers, 1962). He classified adopters into 5 categories, plotted against a normal distribution curve (bell-curve). According to Roger's theory, the first 2.5% of the total adopters over time are classified as innovators, the next 13.5% as early adopters, the subsequent 34% as early majority, the following 34% as late majority, and the last 16% as laggards. This results in the cumulative uptake of an innovation over time by a population taking the form of an S-shaped curve – see Figure 3.

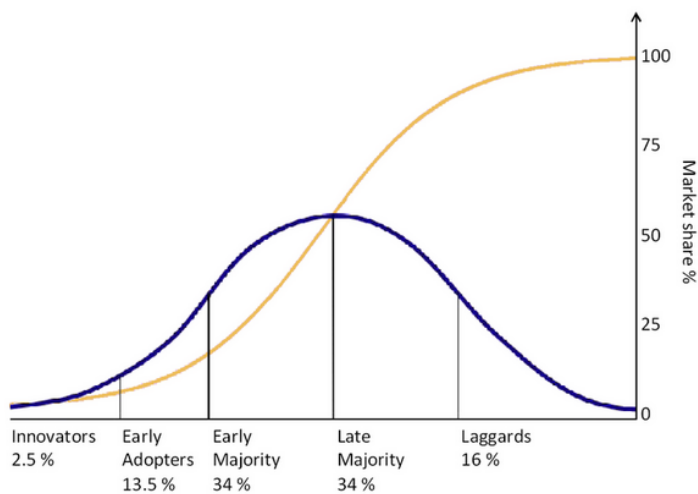


Figure 3: Diffusion of innovations.

Based on: Rogers (1962)

Our focus in this thesis is not the diffusion of a healthcare innovation, but the processes which influence adoption (although the two are related). However, Rogers acknowledged five factors that are nevertheless potentially important for influencing the adoption of the technology in question in this research:

- Trialability – the degree to which a product may be experimented with on a limited basis.
- Compatibility – the degree to which a product is consistent with the users' context, in particular their values and experiences.
- Observability – the degree to which product usage and impact are visible to others.
- Relative advantage – the degree to which a product is better than the product that it replaces.
- Complexity – the degree to which a product is difficult to understand and use.

Geoffrey Moore expanded the theory on diffusion of innovations by focusing on the characteristics of the potential adopters (e.g. values, attitudes, and interests), which he sees as essential to the uptake of the innovation (Moore, 1991). In his book “Crossing the Chasm” he argues that encouraging sales and enthusiastic reviews from innovators and early adopters (which have specific characteristics) are usually not enough to stimulate widespread adoption, and that reaching the early and late majorities is key to achieving commercial success. The gap that is often seen to exist between early adopters and the early majority was termed by Moore the innovation ‘chasm’.

As mentioned in the section on health innovation (see Section 2.1.3), hard and soft health technologies often interact together as part of a *complex technology system*. Therefore, innovations in healthcare have been conceptualised as having a ‘hard core’ (the hard technology) and a ‘soft periphery’ (the organisational structures and systems required for the full implementation of the innovation) (Greenhalgh et al., 2004b). Hence, the adoption and diffusion of most innovations in healthcare is strongly correlated with organisational changes.

Chapter 2

The above mentioned theories on adoption and diffusion of innovation, as well as other well-known models in this sector, focus very much on the perspective of individual adopters, rather than the adoption and diffusion of innovation by organisational or wider system levels (Greenhalgh et al., 2004b). The latter perspective is crucial for the examination of adoption and diffusion patterns in any public sector and especially in healthcare. Health systems and organisations within health systems (e.g. hospitals) often have complex internal structures that will influence the adoption and diffusion of innovation within them. This can result in innovation processes for which conventional lessons about how innovation takes place in other industries do not necessarily apply.

Research suggests that a number of organisational characteristics are supportive of health innovation adoption (Greenhalgh et al., 2004b), notably the presence of strong leadership, visionary staff in key positions, and culture that is not risk-averse and encourages experimentation. As well as these organisational characteristics, a number of other lessons can also be identified from the existing research:

- The innovation's attributes (e.g. its relative advantage, complexity, trialability, and compatibility with the culture of the adoption system) are significant influences on adoption (Greenhalgh et al., 2004b, Denis et al., 2002).
- While mass media and other impersonal channels may create awareness of an innovation, interpersonal influence through social networks seem to be a critical mechanism for diffusion of an innovation within healthcare (Greenhalgh et al., 2004b).
- The impact of power, the way it is distributed amongst healthcare stakeholders, as well as the politics of healthcare may play a part (Fleuren et al., 2004)
- The way the decision making process is organised in a health system (e.g. centralised vs. decentralised, formal vs. informal) has an influence (Ferlie et al., 2005).

- Long- and short-term consequences of innovation may be substantially different and may be taken into consideration in the adoption decision – payback over a very long time period may be seen as detrimental (Hendy and Barlow, 2012).

2.1.5 Scaling up innovations in health systems

As well as the literature on adoption and diffusion of innovations – both in healthcare and more general – there is research on the notion of ‘scaling up’ as a specific part of the diffusion phase of innovations. Although the notion of scaling up of public health interventions is not new in itself (Mangham and Hanson, 2010), its application to the implementation of innovative health technologies has gained traction over the past decade. Many international organisations have set universal access to healthcare services via the scaling up of resources, innovative interventions and best practices as a key agenda point (WHO, 2013b, The Global Fund, 2011). Nevertheless, no consensus on terminology and definition (Mangham and Hanson, 2010, Subramanian et al., 2011), or framework for analysing scaling up in the healthcare context, has been agreed upon (Simmons et al., 2007).

In literature, the term ‘scaling up’ of healthcare innovations is often used to describe the ambition or the process of:

- Expanding the geographical coverage of projects, programmes, and interventions for the improvement of health – reaching out to a higher number of people (Mangham and Hanson, 2010, Bloom and Ainsworth, 2011);
- Expanding impact and becoming sustainable in multiple dimensions, including quantitative, functional, organisational, and political terms (Mangham and Hanson, 2010);
- Increasing capacity (Bloom and Ainsworth, 2011);
- Increasing mobilisation, empowerment, and collective action at grassroots level (Binswanger and Aiyar, 2003);
- Institutionalising certain best-practices and approaches (Bloom and Ainsworth, 2011).

The process of scaling up often refers to two broad perspectives (Bloom and Ainsworth, 2011):

- Enlarging the reach and broadening scale of predefined global goals (e.g. MDGs) - often used in the mainstream global health policy scene;
- The roll out of small-scale interventions and their transformation into large programmes – often using blueprint approaches.

According to the WHO, scaling up in the health sector means “doing something in a big way to improve some aspect of a population’s health” (WHO, 2008a). It can be applied to scaling up inputs, outputs (access, scope, quality, efficiency), outcomes (coverage, utilisation), or impact (reducing morbidity or mortality) (WHO, 2008a).

In this PhD study, the term ‘scaling up’ is used to represent the process of enlarging the coverage of health interventions or technologies, by leveraging the financial, organisational and human resources as well as national and international policies required to achieve their pre-set goal. It is therefore seen as part of the diffusion process.

2.1.6 Scaling up of health interventions in low-income countries

The HIV/AIDS pandemic in the late 1990s focused the attention of developed countries onto the need to provide universal access to antiretroviral therapies for HIV-infected individuals and further developed their urgency to engage globally in activities of prevention, testing, treatment, and care of the disease in low-income countries (Mangham and Hanson, 2010, Binswanger, 2000). The adoption of the Millennium Development Goals (MDGs) by the UN in the year 2000 (UN, 2000) raised the awareness of the necessity to increase international development efforts and improve global health (Mangham and Hanson, 2010). Additionally, it was highlighted that despite the extensive use of technology in the health systems of high-income countries, people from middle- and especially from low-income countries often lack essential drugs, devices, and services (Howitt et al., 2012). This

has a severe impact on the discrepancy in life expectancy and is seen as a consequence of poverty on health (WHO, 2008b).

Through these awareness campaigns the volume of international financial aid has risen steeply, channelled via a number of initiatives that have begun in the healthcare sector (Bloom and Ainsworth, 2011, Nirmala Ravishankar, 2009). The development assistance for health (DAH) grew from USD 5.6 billion in 1990 to USD 21.8 billion in 2007 (Nirmala Ravishankar, 2009). The need to allocate resources properly, with careful consideration of achieving successful implementation, has raised the importance of scaling up interventions in disease endemic countries.

Many of the previously mentioned peculiarities of the healthcare sector (e.g. strong regulation, many stakeholders) (see section 2.1.1) are present to different extents in the markets of resource-challenged and disease-endemic countries, and need to be taken into consideration when thinking of scaling up healthcare intervention in those areas.

In low-income countries, an additional layer of complexity is added by the fact that the intermediary bodies (including doctors and hospitals), the organisational bodies, and the regulatory bodies are sometimes only partially or not at all developed (Bloom et al., 2009). Especially in Africa, this is strongly dependent on how the individual countries transformed from their post-colonial beginnings via the post-revolutionary Africa (Bloom et al., 2009). For example, a substantial number of countries have seen a prompt spread of the goods and services related to healthcare, but a much slower development of the necessary institutions. Additionally, private for-profit and non-for-profit organisations have taken the lead in distributing goods and services related to healthcare, thus blurring the boundaries between public and private sectors.

In addition to this layer of complexity within the health system, the speed of uptake of health innovations in such countries may be affected by political instability, strong inequalities, high dependency ratios, and fragmented administrative and regulatory institutions, all leading to extreme complexity of the environment for innovation adoption.

Finally, slow adoption and diffusion of health innovations in low-income countries is often also linked to “the way the problem, which the innovation is designed to address, is perceived by the individuals and the adoption system within health institutions, the health system and the broad context” (Atun, 2012).

For this reason, exhaustive mapping of the health system – its institutions, governance structure, and processes – prior to intervention planning is essential, in order to help tailor the scaling up approaches to the local contextual features (Howitt et al., 2012). The current body of research stresses a set of key issues to scaling up which are essential for the successful implementation of healthcare technologies in low-income countries, with important lessons for the proposed case study (see Chapter 6). The literature highlights prerequisites for the successful implementation of health technologies in low-income and disease-endemic countries:

- An awareness of the nature of possible barriers to scaling up is essential (Mangham and Hanson, 2010). These barriers can occur at various levels: community level, health service delivery level, health sector policy and strategic management level, and environmental and contextual characteristic level.
- It is important to ensure the organisational readiness of the adopting system (Cooley and Kohl, 2006). Amongst other actions, this includes the readiness of the socio-political and cultural context to uptake the innovation (Binswanger, 2000).
- Throughout the adoption, diffusion and scaling up phases, it is very important to ensure sustainability of the proposed intervention (McGuire et al., 1988d, Gilson et al., 2001). Many papers highlight the need to understand the complexity of the proposed healthcare intervention (Gericke et al., 2005) and to try to keep things as simple as possible (Yamey, 2011, Harries et al., 2009).
- Often adaptation of the technology to local needs and cultures is necessary (e.g. colour and shape of insecticide treated nets (ITNs) has an impact on its uptake, see Chapter 5) (Simmons et al., 2007, Howitt et al., 2012). The

technology may need to be adapted and designed to local conditions to have a good performance and long lifespan in determined (often extreme) conditions (e.g. high temperatures). This comprises not only the tailoring of specific technical features of the technology to the local setting, but also the customisation of its deployment strategies (Gilson and Schneider, 2010).

- Some studies suggest the use of local evidence and regional best practices as models to tailor implementation strategies (Bastiaens et al., 2014, Rowe et al.).
- The active shaping of advocacy to create and support political commitment to the proposed healthcare intervention (Gilson and Schneider, 2010) is also fundamental. This enables the involvement of key political figures at all levels of the system (Díaz, 2007). It also supports the creation of evidence-informed policies to fortify health systems and improve their receptivity to innovation (Atun, 2012). In fact, having scientifically robust technical policies in place before the start of the scaling up of the proposed healthcare intervention (Yamey, 2011) is identified as a key enabler of the process. Further, advocacy to shape feasible financial models is also central. Micro credit schemes have proven helpful in reaching people formerly excluded from the organised economy (Greeley, 2006).
- Especially in the case of complex technologies, enhancing knowledge transfer and developing strategies to overcome human resource constraints (Mangham and Hanson, 2010) is seen as key to the scaling up process. Adequate expertise transfer and training of the appropriate staff and citizens will improve the implementation at community level (Bastiaens et al., 2014, Rowe et al.). Further, if needed, training at national level is seen as important to ensure safety and quality of practices and services. To support this process, unambiguous messages and guidelines on the technology and its deployment need to be adapted to the local context to ensure translation from change in policy to a change in routine practice (Bastiaens et al., 2014, Rowe et al.). This will also help to clearly describe the advantages of the proposed technology compared to other technologies with the same scope to the staff delivering it as well as to end-users adopting it. Further mobilisation of the necessary

resources for training and monitoring of staff is seen as key to ensure consistent quality at all levels (Bastiaens et al., 2014, Rowe et al.).

- Engagement with local, national and international stakeholders in all phases of the scaling up process (Yamey, 2011, Simmons et al., 2007) is viewed as a critical issue. This task is not simple as every stakeholder group approaches the problem and therefore the 'scaling up task' from different (and possibly subjective) perspectives, needs and interests (Bloom and Ainsworth, 2011). Therefore, they require different forms of engagement. Further, the stakeholders interact between one another in a 'context of unequal power relationships' (Bloom and Ainsworth, 2011), thus influencing each other. For greater global acceptance of the technology, the involvement of citizens at every stage and level is crucial (Binswanger and Aiyar, 2003). Authors often emphasise the importance of fostering engagement with the local health system to understand to what extent it is able to deliver the interventions on the ground (WHO, 2007). Further, the involvement of non-state healthcare providers such as NGOs and private-for-profit organisations (e.g. private health workers) to extend outreach (Patouillard et al., 2007, Palmer et al., 2003, Goodman et al., 2007) is looked upon favourably. In fact, these stakeholders often play a crucial role in delivering health services across Africa and should therefore be engaged early on (Hetzl et al., 2008, Chuma et al., 2010).
- Finding an appropriate delivery system for the proposed health intervention is viewed as indispensable to scaling up in terms of expanding the geographical reach (Mangham and Hanson, 2010, Ooms et al., 2008). This is highly dependent on the type of intervention to be scaled-up and on the contextual framework found on the ground. Ensuring constant availability and supply of treatment in rural areas (Bastiaens et al., 2014, Rowe et al.), where access to services is low but necessity for services may be at its highest (WHO, 2013c), is a significant challenge for many projects in low-income countries.

- The use of cascade and phased approaches for the expansion and scaling up of healthcare interventions in low-income countries has often proved to be crucial for healthcare programmes (Yamey, 2011, Renju et al., 2010, Binswanger, 2000). In some cases, the replication and adoption of pilot studies in more resource-constrained settings and the subsequent adjustment of the scaling up strategy have proven to be very useful before enlarging the reach (Bloom and Ainsworth, 2011).

2.2 Discussion

In this chapter, the author examined existing systematic reviews of the literature on the adoption of innovation in healthcare, as well as additional relevant texts on the adoption, diffusion, and scaling up of health technologies. Literature on scaling up in low-income countries was also included, due to its importance in the global health domain, its relationship with the adoption and diffusion process of health technologies in those countries and relevance to this PhD thesis.

It became clear that health systems have very specific structural characteristics and dynamics which lead to an intrinsic complexity which cannot be ignored. This is especially true for health systems of low-income countries, where the features leading to complexity are accentuated. Furthermore, lessons learned from scaling up in low income countries also show that contextual factors have a strong influence on the dynamics and speed at which innovations are taken up, and should not be disregarded.

Hence, when looking at frameworks to analyse the adoption of health technologies within health systems it is important to avoid reductionist and linear perspectives on the dynamics of adoption and diffusion as they can lead to a simplistic analysis and misinterpretation of the challenges in introducing health technologies. It is important to choose an approach based on systems thinking that acknowledges the various layers of complexity and takes them into account without overlooking the dynamics between health system, wider context, and the characteristics of the

technology itself. The choice of such a framework for this PhD study is discussed in Section 4.4.4.

The literature on health technologies and innovations also exposed the need to precisely define specific characteristics of the technology analysed – i.e. hard and soft components as well as the degree of novelty and innovativeness – in order to be able to understand the possible pathways for its adoption within a specific health system. For this reason, Chapter 6 includes a detailed analysis of the characteristics of the case study's technology.

Finally, it became apparent that despite the large volume of studies on adoption and diffusion of health innovations, there are a number of limitations to the current body of research which need to be taken and addressed. These are described in the next chapter, together with the research questions that will be addressed within this PhD study.

3 Research question

3.1 Research gap

Despite the large volume of studies on adoption and diffusion of health innovations, there are limitations to the current body of research. Apart from a lack of consensus on terminology associated with ‘adoption’, ‘implementation’, and ‘diffusion’ – especially in the context of global health (Simmons et al., 2007, Cooley and Kohl, 2006) - there are biases in existing studies. Historically there has been an emphasis on the perspective of the *individual user* and on comparatively *discrete, bounded innovations* (e.g. a new bednet), rather than on more *complex innovations*, with multiple attributes and involving several institutional or governmental stakeholders in adoption decisions (Greenhalgh et al., 2004b). Such innovations may be far less clear cut than those which are well-defined and are adopted by a single organisational unit (e.g. a single device adopted by a single hospital) or an individual consumer. As a result, until fairly recently relatively few studies sought to explain adoption holistically, taking into account the complexity and dynamics of health and wider adoption systems (Atun, 2012, Frambach and Schillewaert, 2002, Greenhalgh et al., 2004b).

Further, studies often assume that the findings of adoption and diffusion research are transferable to new contexts and settings without alterations (Greenhalgh et al., 2004b). Studies which compare procedures in different countries and contexts are rare (Frambach and Schillewaert, 2002). But especially in the healthcare sector, the response to the same technology can be very different (WHO, 2011), depending on the context, notably the structure of the health system and the interaction between the technology and the system as a whole (Atun, 2012).

These limitations are mirrored in research on the adoption of malaria elimination and GM technologies. Studies focus on the implementation of relatively simple discrete innovations such as bednets and anti-malarial tablets, which are adopted by individual users (see Chapter 5 for a detailed discussion) (Teklehaimanot et al., 2007, Lines et al., 2003, Hanson et al., 2008, Pitt et al., 2012). Nevertheless, there is an awareness that the successful introduction of these innovations requires the

design of context-specific programmes which include interventions at multiple levels; there are calls for a better understanding of implementation of malaria technologies (Mulligan and Conteh, 2016). The very limited literature on the adoption and implementation of GM technologies, whether aimed at health or agriculture, points to the need for a holistic understanding of the adoption barriers and intervention at multiple levels (see Chapter 5).

3.2 Research aims and questions

Given the research gaps identified above, the overall aim of this PhD study is to develop a deeper understanding of the specific factors which underpin adoption and implementation *when both the technology and the adoption context are highly complex*.

This PhD therefore explores the adoption and implementation of a complex health technology (GM mosquitoes) targeted at a specific health problem (malaria) in a specific health system (Burkina Faso). This requires an approach that uses a framework that takes the complexity of health systems and their dynamics into consideration, as well as the interaction between the innovation, the intended adopters, and the particular context for adoption (Atun, 2012, Frambach and Schillewaert, 2002, Greenhalgh et al., 2004b).

Specifically, the PhD study is addressing the following research questions:

- **Who are the key actors involved in the adoption process and what are the dynamics of the interactions between them?**
- **How do contextual factors influence the adoption process?**
- **How does the adoption and implementation process for complex innovations that involve decisions by multiple stakeholders compare with innovations that involve individual decisions?**

Chapter 3

This study therefore aims to contribute to the body of research on adoption and implementation of health innovations. In addition, it will help to inform policy makers, technology developers and health professionals on the factors and dynamics which enhance the likelihood of successful adoption of complex technologies.

Chapter 3

4 Methodology

This chapter discusses the research approach and design for this PhD study as well as the consequent methodological choices that were made. Section 4.1 discusses the epistemology and the research approach of the overall PhD study, while Sections 4.2, 4.3, and 4.4 respectively describe the research strategies for the systematic health system and context analysis, the econometric analysis and the qualitative single case study respectively. The last part of this chapter (see Section 4.5) describes how the author ensured that the basic principle of research ethics and Target Malaria's ethical policy requirements were fulfilled throughout all the data collection and analysis process.

4.1 Overall PhD study research approach and design

4.1.1 Epistemological stance

The first step to define a robust methodological approach was to determine the best epistemological paradigm and define the appropriate methods of analysis. An epistemological paradigm is defined by Guba et al. as the 'the basic belief system or worldview that guides the investigator' (Guba et al., 1994).

The current body of literature is centred around two main antithetical epistemological paradigms: positivism and constructivism (Guba et al., 1994). The positivist paradigm postulates that the real world should be investigated by the natural sciences and that it can be quantified (Lincoln and Guba, 1985). The goal of positivist research approach is to enlighten reality as well as to predict and regulate phenomena (Guba et al., 1994). Because of its intrinsically objective nature, the positivist paradigm is well suited to non-complex situations where clear contextual boundaries are present (Guba et al., 1994).

The constructivist paradigm, on the other hand, rests on the assumption that both world and individually perceived reality are mental constructs, primarily constructed and then interpreted by people (Taylor and Bogdan, 1984). This

approach is considered to be more appropriate for the analysis of complex and context-sensitive situations (Taylor and Bogdan, 1984).

The technology development and adoption process addressed in this PhD thesis is complex, with many stakeholders involved both in development and adoption (as described in Chapter 2). It also needs to be placed into context, as judgements about adoption are made in a specific country, health system and organisational setting. Hence, a constructivist approach may have been deemed to more appropriate. In the past, the interpretive nature of such an approach was criticised for being exploratory, non-scientific, personal and biased (Denzin and Lincoln, 1998). For this reason, this type of research was not widely used until fairly recently, especially in health research (Denzin and Lincoln, 2011, Pope and Mays, 1995). Nevertheless, because of its ability to analyse the complex and subjective nature of many phenomena, more constructivist qualitative research methods have been increasingly adopted (Guba et al., 1994).

Pragmatism and a mixed methods approach

With an increasing volume and complexity of available research data, the constraints of mainstream 'single-method' approaches have become always more apparent. As a result, multimethodology or methodological pluralism have become an increasingly important part of the research landscape (Tashakkori and Teddlie, 2003, Cameron and Miller, 2017). This is especially the case in the fields of applied social science, as well as in the growing body of trans-disciplinary literature.

'Mixed methods research' is a methodology that incorporates the collection, analysis, interpretation and integration of both quantitative (e.g. experiments, surveys) and qualitative (e.g. focus groups, interviews) research (FoodRisc Resource Centre, 2016) in a single study or in a series of studies that investigate the same underlying phenomenon (Leech and Onwuegbuzie, 2008). Such an approach can provide a better understanding of the research problem. Further, by combining both quantitative and qualitative research and data, the researcher can improve the breadth and depth of problem comprehension and corroboration, while balancing

the weaknesses related to the use of a single approach (FoodRisc Resource Centre, 2016, Creswell and Plano Clark, 2007).

Several authors propose pragmatism as the underlying paradigm of a mixed methods research. Pragmatists reject the forced choice between positivism and constructivism and take methodological decisions based on the research question and the stage of the study (Tashakkori and Teddlie, 2003). Pragmatism supports the use of both qualitative and quantitative methods in the same study and dismisses the incompatibility stance (Tashakkori and Teddlie, 2003, Maxcy, 2003).

Based on these considerations as well as on the identified research questions for this PhD study, a pragmatic research paradigm was deemed most appropriate, paired with a mixed methods approach. Two main factors led to this choice. The first was pragmatic, related to the stage of the PhD study as well as the development of the Target Malaria project (i.e. the research case study).

At the beginning of the PhD study, the original aim was to incorporate and compare different cultural and contextual perspectives. Literature on adoption of public health interventions in low-income countries points out the importance of the local context in which the studies are undertaken (Howitt et al., 2012). The novel technology developed by the project was originally supposed to be deployed in four countries with very different contextual features (Mali, Uganda, Burkina Faso and Kenya) (see Chapter 6). This would have potentially enabled the impact of differing national contextual features to be investigated. The political instability in Mali and the fact that Uganda started as a 'back-up' site meant that the author originally intended to focus on Burkina Faso and Kenya. These are not only culturally very diverse, but have also different political, regulatory and public health systems. In addition, the epidemiology of the disease varies in the two countries (WHO, 2013c) (see Sections 12.10, 12.11 in the Appendix), and so does the perception of the malaria problem. However, due to a change in the local senior management and hence in the strategic approach of the partnering institution in Kenya, the partnership with Target Malaria was terminated in advance, allowing only for a very limited analysis of the current situation in that country. Due to this, the author opted for a deeper analysis of the technology introduction in a single country, Burkina Faso.

This led to the second decisive factor in choice of research approach. The greatest advantage of conducting mixed methods research is the possibility of triangulation, i.e. the use of several means (e.g. data sources, data collection and analysis methods, as well as researchers) to examine the same phenomenon from different perspectives. Triangulation allows the researcher to identify aspects of a phenomenon more accurately by approaching this phenomenon from different vantage points using different methods and techniques (FoodRisc Resource Centre, 2016). Hence, the author decided to enhance the qualitative study on the key factors influencing the development and adoption processes of Target Malaria's GM mosquitoes in Burkina Faso by including a quantitative econometric analysis of the socio-demographic factors influencing the adoption of previous malaria prevention methods within the same context (Chapter 8). This was therefore designed to enhance the strengths and diminish the weaknesses in both qualitative and quantitative approaches within the study (Andrew and Halcomb, 2006).

4.1.2 Mixed methods design strategy

Creswell et al. (2003) proposed 'Six Mixed Methods Design Strategies' based on the implementation sequence of data collection, the prioritisation of the data collection and analysis methodology, the integration stage of the findings, and the eventual use of a theoretical perspective: sequential explanatory, sequential exploratory, sequential transformative, concurrent triangulated, concurrent nested, and concurrent transformative (Table 1).

Type of design	Stage of integration	Implementation	Priority
Sequential explanatory	Interpretation	QUAN → qual	Usually QUAN, can be QUAL or equal
Sequential exploratory	Interpretation	QUAL → quan	Usually QUAL, can be QUAN or equal
Sequential transformative	Interpretation	QUAL → QUAN	Either dominant or both equal
Concurrent triangulated	Interpretation or analysis	QUAL + QUAN QUAL + quan QUAN + qual	Either dominant or both equal
Concurrent nested	Analysis	Qual () QUAN quan () QUAL	Either dominant
Concurrent transformative	Usually analysis, can be interpretation	QUAL + QUAN	Equal

Table 1: Overview of ‘Six Mixed Methods Design Strategies’.

Based on: Creswell and Plano Clark (2007). Mixed methods notations based on Morse (1991): QUAN or quan refers to quantitative; QUAL or qual refers to qualitative; use of upper case refers to emphasis, primary or dominant method; use of lower case refers to lower emphasis or non-dominant method; ‘→’ refers to data collected sequentially; ‘+’ refers to data collected simultaneously; ‘()’ refers to one method embedded in the other. Highlighted in red: the chosen research design for this PhD study.

For this PhD study, the author decided that choosing a concurrent triangulated mixed methods approach with a partially nested health system and context analysis was appropriate. The main driver for this decision was that the qualitative research on Target Malaria’s technology, involving stakeholder interviews and analysis of primary and secondary documentary data, would be enriched by a quantitative econometric analysis of the adoption of different types of malaria eradication technologies in Burkina Faso. These two studies were performed concurrently and each study informed the other. This work was complemented by an extensive analysis of the Burkinabé health system and socio-economic and policy context, based on primary and secondary data. This provided a deeper understanding of the cultural and stakeholder landscape, needed both for the design of the PhD research approach and for further substantiation of the data and results. Hence, the health

system and context analysis (Chapter 7), and the quantitative econometric study (Chapter 8), were used to enhance, validate and corroborate findings from the qualitative case study (Chapter 9).

Figure 4 summarises the relationship between the different studies conducted as part of the PhD study and the way they relate to the thesis research questions.

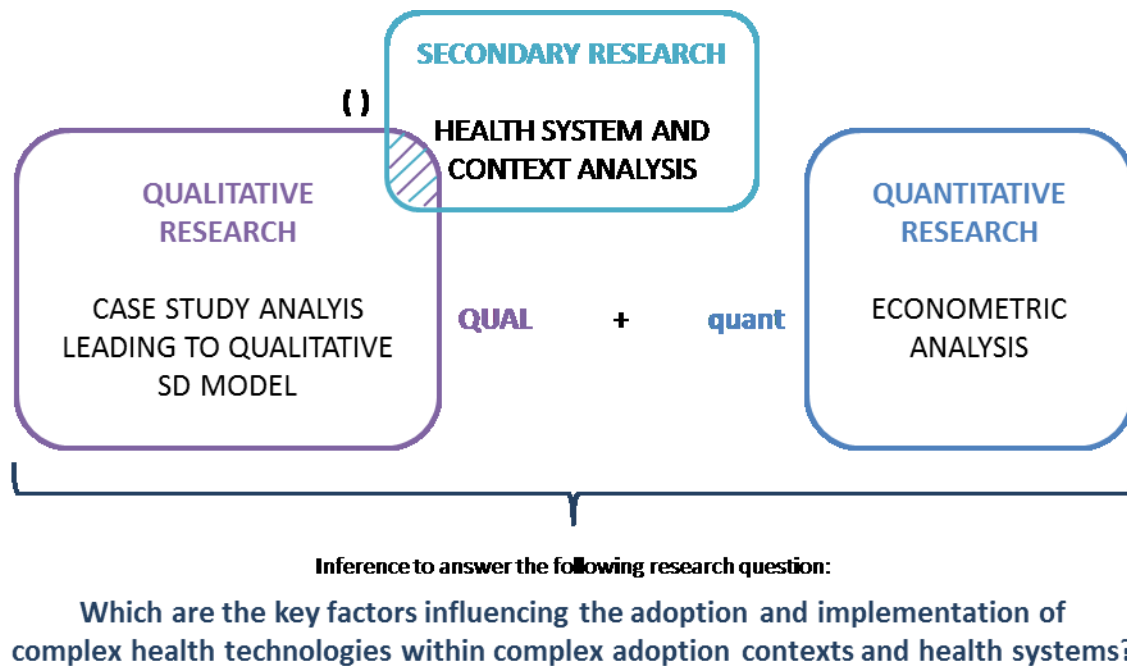


Figure 4: Overview of the triangulated mixed methods research design of the PhD study.

QUAL refers to qualitative; quant refers to quantitative; use of upper case refers to emphasis, primary or dominant method; use of lower case refers to lower emphasis or non-dominant method; '+' refers to data collected simultaneously; '()' refers to one method embedded in the other.

The next sections discuss in detail the research approach and methodology for each of the three individual sections of the overall PhD study: the systematic context and health system analysis, the econometric study, and the case study of GM mosquitoes adoption and implementation in Burkina Faso.

4.2 Systematic context and health system analysis

Prior to developing a qualitative SD model and the econometric study, the author conducted a thorough analysis of the context and the health system in Burkina Faso. This analysis was tailored to the needs of the PhD study and based on the approaches of Atun et al. (2013), Frenk (1994), Hsiao (2003), the WHO (2000b), and others (Roberts et al., 2004, Samb et al., 2009, Atun et al., 2006) for the analysis of health systems.

The author adopted a systems approach to analyse the contextual factors and health system functions that interact to influence the achievement of health policy goals or the outcome of interventions (Atun et al., 2013). In this analysis, the context refers to various environmental interdependencies which have the potential to impact the health system. These factors are further specified in Chapter 7. The analysis was mainly performed using secondary data, but was also enriched with insights gained from the semi-structured interviews. Further, some of the results influenced the qualitative study, thus creating the 'nested' nature of the two.

It was therefore possible to precisely describe the overall landscape in which Burkinabé malaria eradication programmes have been realised and in which the case study was being implemented during the time of the PhD study (and still is). The analysis also allowed the author to describe a preliminary stakeholder landscape, which was enriched with the expertise of the local stakeholder engagement team as well as later through a snowballing sampling process.

Furthermore, this analysis helped to provide background information on a culturally remote context and health system, which in return informed the topic guide for the qualitative research study and the system dynamics modelling (see Section 4.4.5).

4.3 Quantitative econometric analysis of the adoption of other malaria eradication technologies in Burkina Faso

Given the mixed methods research approach, the author decided to extend and cross-validate the findings from the in-depth qualitative study with a quantitative analysis of the key factors for the adoption of different malaria eradication technologies in Burkina Faso within the last 15 years. This allowed the author to:

- Gain an objective and independent overview of the key enablers and barriers to the adoption of other malaria eradication technologies within the same context;
- Capture ex-post data which was not possible with the case study as the Target Malaria project was in progress at the time of this PhD study (and still is);
- Triangulate of the results from this analysis with the qualitative results from the case study;
- Better understand the triggers for the adoption of private goods as they were potentially important for understanding the acceptance of public goods like GM mosquitoes.

4.3.1 Data collection for the econometric study

The quantitative econometric analysis analysis was based on socio-demographic and population health surveys of Burkina Faso from *The Demographic and Health Surveys (DHS) Program*, funded by the U.S. Agency for International Development (USAID). The Burkina Faso data used for this PhD study covers the years 2003, 2010 and 2014. Like for most sub-Saharan African countries, the technologies covered in these datasets are mainly simple, commercially available private goods technologies like bednets. Data on public goods technologies like indoor residual spraying or larval control is limited, as until now there have been only a few trials attempting to deploy such technologies in Burkina Faso. Nevertheless, it was expected that the analysis of DHS data for Burkina Faso would yield interesting insights into the cultural, socio-demographic, geographic, and economic enablers and barriers to the adoption of malaria technologies. This still allowed for a comparison of the factors

influencing the uptake of technologies that are relatively simple and involve individual adoption decisions in relations to the key factors for more complex technologies with societal adoption like for Target Malaria's technology.

4.3.2 Data analysis for the econometric study

The analysis of the datasets involved merging, cleaning, recoding and weighting data in order to explore the relationships between outcome variables and independent variables relating to the use and uptake of different malaria prevention methods (see Section 8.1.2). These variables included a range of geographic, socio-demographic, household, economic, and health prevention variables. Based on this data set, three different models were used:

- A discrete choice (logit) model was employed to analyse the behaviour of different units inside the household whenever the dependent variable is binary;
- An ordered logistic model was utilised when the choice of the unit of observation implies some clear ranking amongst the available discrete options;
- A count data model was applied when the dependent variable presents the possibility of a clear ranking of its options and the variable itself belongs to the positive integer domain.

Chapter 8 (Section 8.1.3) contains a detailed description of the modelling and analysis.

4.4 Qualitative single case study

4.4.1 Research strategy for the qualitative single case study

The complexity of health systems and the interaction between an innovation, its intended adopters, and the specific adoption context make it important to select an appropriate framework to guide the development of the study (Atun, 2012, Frambach and Schillewaert, 2002, Greenhalgh et al., 2004b). After a thorough review of several internationally recognised frameworks and discussions with supervisors, the author selected the Atun et. al. (2006, 2010a) framework for the analysis of adoption and diffusion of innovations in health systems. This empirically grounded framework was chosen mainly for its systems thinking approach and its broad flexibility - allowing for adaptation in relation to the Burkinabé context and the innovative technology in question. This framework is described in detail in Section 4.4.4 below. The framework helped the author to develop a tailored topic guide (see Section 4.4.5). In parallel, a stakeholder map of the relevant Burkinabé health policy and provision landscape was created and validated together with the local Target Malaria team (see Section 4.4.6).

Upon the finalisation of the topic guide and stakeholder landscape, a semi-structured open-ended interview guideline (questionnaire) was developed for each stakeholder cluster (see Section o).

The author travelled to Burkina Faso six times during the period of this study to collect and validate the data. In total 74 study participants were formally interviewed (see Section 4.4.8). The collected information was transcribed verbatim and analysed, coded and clustered using a simplified version of the coding system by Strauss and Corbin (Strauss, 1987, Corbin and Strauss, 2008) (see Section 4.4.9).

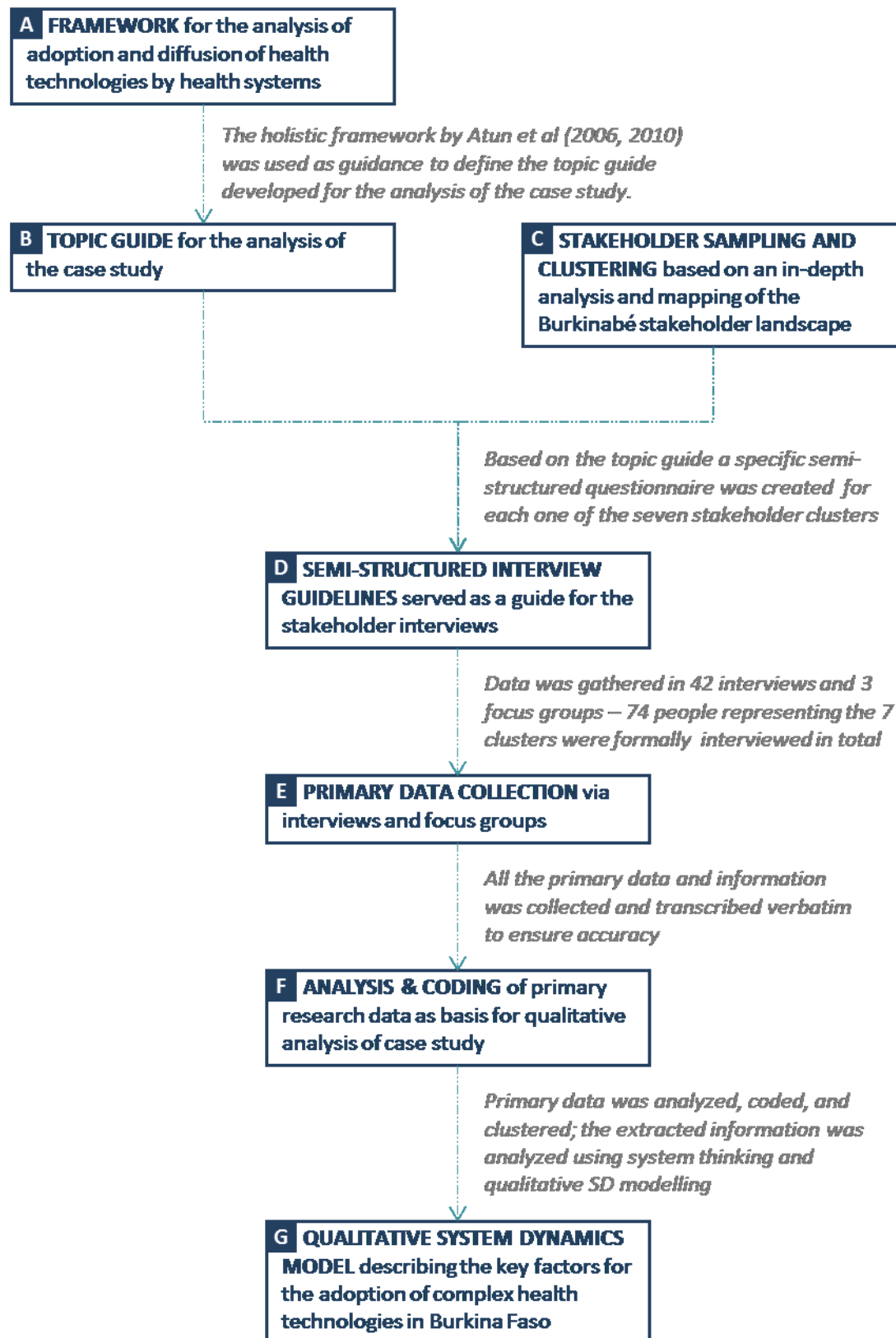


Figure 5: Overview of the data collection and data analysis methods used for the qualitative research study.

Appendix 12.3 shows a figure better detailing steps A to E.

The extracted information was then analysed using systems thinking and qualitative system dynamics modelling. This involved starting with a causal loop diagram method (Azoulay et al., 2010, Sterman, 2000) to investigate the relationships within the emerging themes and to generate an explanation of the identified dynamics (see Section 9.1.2). This work culminated in the creation of a qualitative system dynamics model (Dattée and Barlow, 2017) describing the key factors influencing the development and adoption of Target Malaria's technology, GM mosquitoes for the eradication of malaria, in Burkina Faso (Chapter 9). Figure 5 provides a schematic overview of all the data collection and data analysis steps used for the qualitative research strategy.

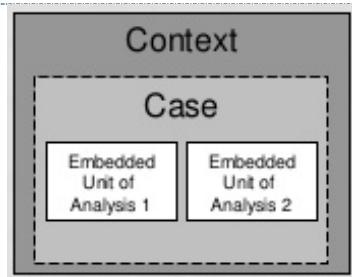
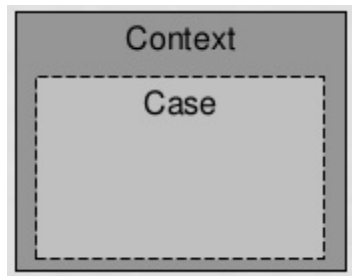
4.4.2 Single case study design

The decision to conduct a single case study to answer the research questions was taken following Yin's approach for method selection (Yin, 1993, Yin, 1994). The aim of this study is not to make comparisons between different technologies or different contexts in order to derive a general theory, but to investigate in detail the factors underpinning the adoption of a complex technology aimed at a specific health problem. A single case study approach was deemed to be appropriate (Atkins and Sampson, 2002) as it allowed the author to engage profoundly in the Target Malaria decision making processes, thus getting as much insight as possible from multiple perspectives. As a result, it was possible to construct a holistic picture of the researched problem. Furthermore, according to Yin, a single case study design is particularly relevant when the case represents an extreme or unusual case, which is certainly the case of GM mosquitoes.

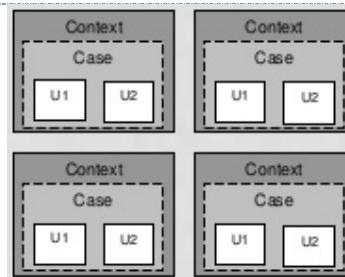
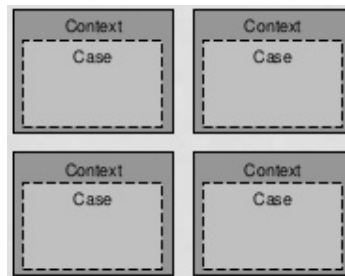
Although the Target Malaria project can be seen as a single case study, multiple units of analysis were nevertheless embedded in the case. The principal unit of analysis is the technology development and adoption process itself. The sub-units of analysis were identified as the innovation characteristics, the adoption system, the health problem tackled by the innovation, and the wider health system. These are

based on the main pillars of the framework selected for the analysis of the case study (see Section 4.4.4). Figure 6 illustrates the chosen case study approach.

A) Single case study design



Multiple-case study design



Single unit of analysis

Embedded multiple units of analysis

B) Single case study design & embedded multiple units of analysis

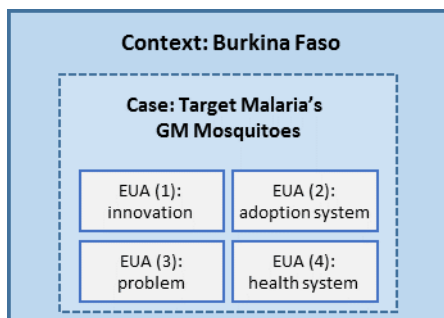


Figure 6: A) Outline of possible case study designs. B) PhD thesis study design.

Based on: Yin (2003). EUA: embedded unit of analysis.

Given the epistemological and research approach of the qualitative study, the most suitable research strategy was to take an inductive rather than a deductive approach. An inductive approach is concerned with the generation of new theory emerging from the data while a deductive approach is aimed at testing an existing or proposed theory. The author's aim was to induce theory from a detailed single case study and

to ground that theory by comparing the emerging ideas against the extant literature (Glaser and Strauss, 1967, Eisenhardt, 1989, Pettigrew, 1997). The research strategy drew on the principles of grounded theory – a systematic methodological approach involving the construction of theory through the analysis of data where there is a continuous interplay between data collection and analysis, leading to the incremental development of new knowledge (Strauss and Corbin, 1994). Such an approach helps to elicit understandings about patterned relationships between stakeholders and how these relationships and interactions actively construct reality (Suddaby, 2006).

4.4.3 Data sources

In order to increase the validity of the findings, the data was collected from various sources following Yin's approach to multiple sources of evidence (Yin, 1994): semi-structured interviews and focus groups with key stakeholders, additional data collected during field trips to Burkina Faso (including official written documentation), interviews with international regulatory experts, as well as information gathered through the project management activities within the Target Malaria project. The product development stages of Target Malaria's technology in Burkina Faso and its key implications for the adoption process were central to the PhD study. Since technology development was (and still is) continuing as this PhD study was being finalized, observational methods like information gathering through Target Malaria project management activities were used to enrich the findings and data collected. Together, with the different perspectives, know-how, and experiences of the various stakeholders, these multiple sources of data further enhanced the objectivity of the study.

The individual processes are described in detail in Section 4.4.8.

4.4.4 Selection of the framework

The existing literature (Chapter 2) suggests that complexity of many health innovations and of the health systems into which they are introduced means that reductionist and linear perspectives on the dynamics of adoption and diffusion need to be avoided (Greenhalgh et al., 2004b). These can lead to a misinterpretation of the challenges in introducing healthcare innovations and render it impossible to correctly forecast consequences of interactions within the system.

To address these limitations, recent systematic reviews have emphasised the need for more sophisticated models and frameworks. These are built on the assumption that adoption and diffusion of innovation in the healthcare sector is highly dependent on interactions between the innovation, contextual factors, local actors and adopters, as well as the organisational context and its processes (Denis et al., 2002, Greenhalgh et al., 2004b).

The author reviewed several holistic models for analysing the adoption of innovative health technologies by health systems. In light of the findings of the literature review in Chapter 2, it seemed sensible to use a framework that takes the complexity of health systems, its dynamics, and systems thinking into consideration. The empirically grounded framework, developed and tested in different contexts by Atun et al. (2006, 2010a, 2010b, 2012) embraced all these characteristics and was therefore used as the overarching analytical framework of the case study (Figure 7). This framework has four main advantages.

Firstly, compared to other frameworks which are rather prescriptive (Denis et al., 2002, Greenhalgh et al., 2004b), this fairly broad framework gave the author the possibility to adapt and shape it in relation to the Burkinabé context and the innovative technology in question.

Secondly, it gave the author the flexibility to tailor the topic guide and the resulting questionnaire in a context specific way, without losing the boundaries and guidance of a strong and validated holistic framework.

Thirdly, this framework is based on systems thinking, the basis for the creation of qualitative system dynamics (SD) models. This ensured a coherent methodological

rigour flowing from the choice of the framework, through the creation of the topic guide all the way through to the development of the qualitative SD model.

Finally, compared to other frameworks for analysing the adoption and diffusion of health innovations, the Atun et al. framework also takes into account the role of other institutions and adoption entities outside of the health system but within the analysed context. Given the complex nature of the GM mosquito technology, it is reasonable to expect that the adoption decision making will not only be influenced by health system stakeholders (since the only purpose of the release of these mosquitoes is malaria eradication) but that other institutions (i.e. ministry of environment, regulatory bodies) will likely be involved as well.

Within this framework health systems are visualised as open systems, with intertwined components that interrelate with each other within the context in which the health system is located (Atun et al., 2006, Atun, 2012). The components are:

- The broad context (contextual factors);
- The characteristics of the health system in question;
- The institutions within the health system;
- The adoption system (response system) and
- The adoption entities.

These components are inter-dependent and thereby influence the receptivity of the health system to a new innovation (a solution to a particular problem) and the scale and speed of adoption and diffusion. Interactions between the components have either amplifying or balancing effects on each of the components, thus creating a network of feedback loops in response to adaptation. The ensemble of these feedback loops determines the system's behaviour. The majority of the interconnected and interdependent modules within the health system therefore generate a potentially non-linear response and variable time lags between cause and effect of an action, collectively leading to the formation of complex adaptive systems and dynamic complexity. Thus, a system response does not occur in reaction to the

change of one of the components, but as a result of the interactions between the system's elements. 'Systems thinking' can therefore help to better comprehend these interconnections and complexity, by enabling the author to carefully consider the possible consequences of actions within an overall complex system (Atun, 2012).

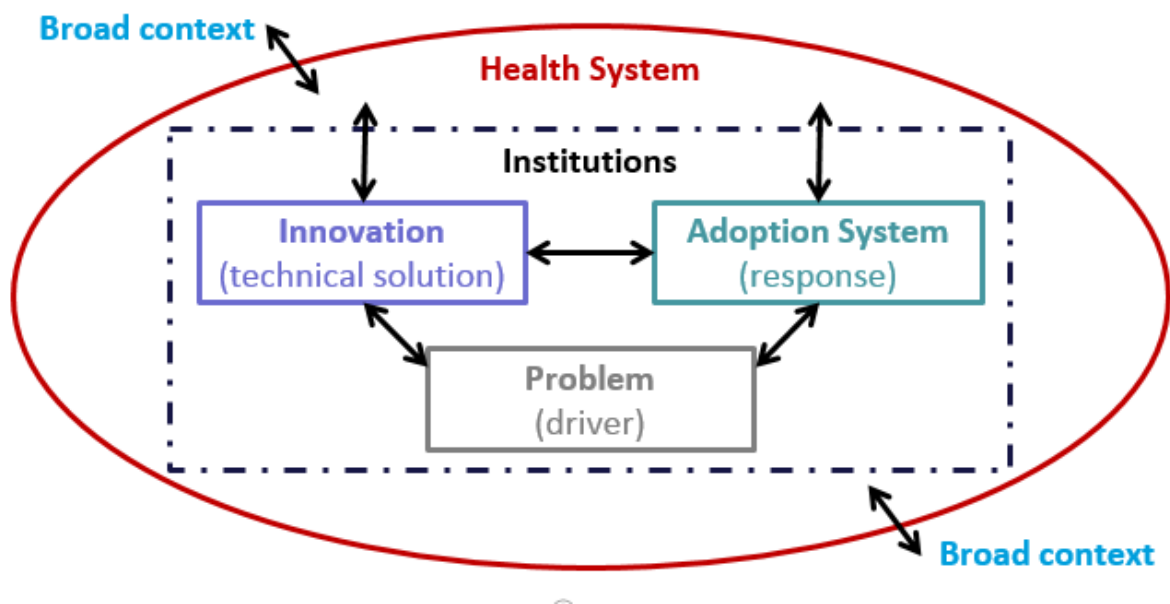


Figure 7: Framework for analysis of adoption and diffusion of innovations in health systems.

Based on: (Atun, 2012).

4.4.5 Development of the topic guide

Since the study incorporated many exploratory elements it was not sensible to structure the interview guidelines before the respective interviews too strictly. Nevertheless, given that the author was using the Atun et al. framework to explore defined topics of interest, the interview process had to be guided consciously using a semi-structured approach and a topic guide (Patton, 2015).

The topic guide developed for the analysis of the research question is based on the main pillars of the Atun et al (2010a, 2006) framework: problem, innovation, adoption system, health system, and broad context. Additionally, some specific questions on malaria and on GM mosquitoes were asked in order to further tailor the interviews to the case study. The overarching themes of the topic guide are represented in Figure 8.

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1. Problem	
1.1	General Problem Perception
1.2	Health problems perception
1.3	General knowledge & perceptions on malaria prevention / treatment of malaria
1.4	Magnitude of the problem: ranking of malaria within health problems and general problems
2. Innovation	
2.1	General knowledge on innovation
2.2	Attitudes towards different types of innovation
2.3	General knowledge on innovations for malaria
2.4	Attitudes towards innovations for malaria
2.5	Diffusion process of malaria innovation (intervention path)
3. Adoption system	
3.1	Structure and nature of adoption system
3.2	Decision making process (within adoption system)
3.3	Decision implementation strategy (within adoption system)
3.4	Links and relations to other systems (e.g. HS) / levels
3.5	General acceptance and attitude towards decisions taken by other systems / at different levels
3.6	Role of power
3.7	Legitimacy in the adoption system
4. Health System (& institutions within HS)	
4.1	Structure of health system
4.2	Decision making process (within HS)
4.3	Policy implementation strategy (within HS)
4.4	Policy implementation strategy for malaria (within HS)
4.5	Deployment strategy of malaria intervention (within HS)
4.6	General acceptance and attitude towards decisions taken
4.7	Links and relations to other systems / levels
4.8	Role of power
4.9	Technical legitimacy vs. normative legitimacy
5. Broad Context	
5.1	Reasons for differential uptake of innovation
6. GM Mosquitoes	
6.1	General knowledge on GM
6.2	General knowledge on GM mosquitoes
6.3	Attitudes towards GM mosquitoes
6.4	Factors influencing adoption and diffusion of GM mosquitoes

Figure 8: Topic guide for semi-structured interviews.

4.4.6 Stakeholder sampling and clustering

The primary objective of sampling individuals and organisations was to achieve a multi-level, broad-spectrum representation of the study population, i.e. relevant individuals and organisations within the chosen context (the Target Malaria project and wider Burkinabé context). Purposive and snowball sampling (Bowling, 2009, Yin, 2011) were used to identify appropriate individuals and organisations as interviewees. Both methods are non-probability sampling techniques. In purposive sampling the samples are chosen in a deliberate manner in order to yield the most

relevant and plentiful data given the research question (Yin, 2011), while in snowball sampling the sample size is extended through networking (Bowling, 2009, Yin, 2011).

A non-random sampling design was chosen over probability sampling because the exact number of elements in the study population was unknown and it was impossible to individually identify all elements of the study population.

The author first conducted an in-depth examination of the health system and socio-economic context in Burkina Faso, together with an exhaustive stakeholder analysis exercise (which was carried out jointly with the Burkinabé Target Malaria team). This resulted in the identification and the mapping of the local, regional, national, and international stakeholders influencing or being influenced by the development and deployment of the technology. The key stakeholders to be interviewed were selected following the principle of maximal and minimum contrasting (Brüsemeister, 2000) in order to cover the entire range of stakeholders represented at local, regional and national levels. This interview sample included government bodies, politicians, international organisations, NGOs, scientific communities, health sector workers, rural community inhabitants and others. This pool of interviewees was used as the principal data source for the analysis of the stakeholder landscape and the development of a stakeholder matrix which served as a basis for the initial, judgemental sample of interviewees. Furthermore, this first selection of the study population was narrowed down jointly with the in-country team based on the following criteria:

- Importance of the stakeholder;
- Influence of the stakeholder;
- Possibility to contact and arrange an interview with the stakeholder;
- Appropriateness of meeting the stakeholder from a Target Malaria project perspective.

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These stakeholders were then clustered into seven groups based on their position in the stakeholder matrix (see Figure 9). In this clustering process, the stakeholders were subdivided according to their geographical and policy reach (local, regional, national, and international), as well as their role within the health system (i.e. healthcare users, technical position within health system such as physician or nurse, managerial position within health system, or policy maker involved in health system). For each of these seven clusters a specific semi-structured interview guideline based on the topic guide, (see Figure 5) was created.

Policy makers			
Managerial	• Dir. regional malaria program • Director of direction regional de la sante (DRS)	• Ministry of Health (minister, cabinet, ...) • Dir. of Plan National de Développement Sanitaire (PNDS) • Dir. National Malaria Program • Dir. other health related programs • Rep. from regulatory body (NBA): Agence Nationale De Biosecurite (ANB), Comité Scientifique National De Biosecurite (CSNB), Observatoire National De Biosecurite (ONB) • Comité d'éthique pour la recherche en santé • Programme national de lutte contre le paludisme (PNLP)	• Rep. from intergovernmental health related organisations on ground (WHO, USAID, Global Fund, ...) • Rep. from Pan-African Health bodies: Organisation Ouest Africaine de la Santé (OOAS), ...
	• Coordinator of local malaria / health interventions • Coordinator of NGO work on ground • Coordinator of CSPs or CMA • Comité gestion (coges) CSPs (management committee CSPs)	• Coordinator of regional malaria / health interventions / vector control programs • Coordinator of regional NGOs • Coordinator of CHR • Rep. of malaria practice at CHR • Coordinator of Private medical practices with broader reach	• Rep. from international health related NGOs on ground (MSF, world vision, ...)
	• Rep. Medical Centre (CMA/ CM) • Rep. Primary Health Centre (CSPs) • Rep. private medical centre • Traditional doctor/ nurse/ healer • Health/ environment NGO worker	• Rep. Regional health centre / district hospital (CHR) • Rep. private medical centre • Rep. District sanitaire	
Technical		• Rep. form CHU Bobo / Ouaga • Scientists/ Rep. from research institution of in-country team • Scientists/ Rep. from other research institutions: Centre National de Recherche et de Formation sur le Paludisme (CNRFP), école nationale de santé publique (ENSP), ... • Secréariat permanente des ONGs	
Users	• Chief of village (Chef de village) • Chief of land (Chef de terres) • Group of Elders • Notables du village • Traditionnelles du village • Représentant de l'ethnie • Groupes ethniques non autochtones (Non-indigenous ethnic groups) • Rep. from civil society groups: youth, women, ... • Religious / faith based leaders: imam, catéchistes, ... • Teachers / Educational • Rep. local police / security • Rep. public transport • Local business / private sector • Entraide culturelle	• Rep. for national non-health / environmental NGOs • Rep. from other relevant Ministries: Environment, Technology and innovation, Ministère de l'enseignement, ... • Rep. from national police • Religious / faith based leaders • Governmental companies • Private sector • Media: rep. Les cahiers de la Présidence du Faso, Association aux individus opposants OGM • Groupements villageois féminins (GVF) • Union nationale des producteurs de coton du Burkina (unpcb)	• Rep. from intergovernmental development organisations on ground: FAO, UNDP, UNHCR, ... • Pan-African bodies: African union, ECOWAS, West African Economic and Monetary Union (UEMOA), ... • International Media (TV5) • International NGOs: Jeune chambre Internationale (JCI – JC/ BF) • International research centers: CIRDES (Centre International de Recherche-Développement sur l'Élevage en zone Subhumide)
Local		Regional	National
		Regional	International

Figure 9: Stakeholder mapping with clusters for judgemental sample selection.

4.4.7 Development of semi-structured interview guidelines

For each of the 7 stakeholder clusters (see Figure 9) distinct semi-structured open-ended interview guidelines were developed based on the topic guide (see Section 12.5 in the Appendix). For example, representatives from the local and regional user clusters were primarily asked about their problem perception and the broad context, while interviews with representatives from the national policymaker cluster focused on characteristics and dynamics of the adoption and health systems.

In order to avoid jeopardising the Target Malaria project by raising expectations or critiques, questions on GM mosquitoes – due to their sensitive and controversial nature – were asked only to individual stakeholders deemed suitable during the interview by both the author and the local project team member.

The ‘technical’ and ‘theoretical’ language used in the framework and in the initial drafts of the topic guide and interview guidelines was very distant from the vocabulary of some of the interviewees, i.e. sometimes terms did not exist in their local language. For this reason, the author conducted several extended sessions with the local stakeholder engagement team and the local translator in order to tailor the questions and especially the wording used for the specific stakeholder cluster or even individual interviewees.

Following grounded theory methodology, the interview guidelines were not submitted to the interviewee, but questions were asked iteratively based on the feedback received by the interviewee, thus retaining its semi-structured character. All formal interactions with the study population were digitally recorded.

4.4.8 Primary data collection

Given the geographical distance and remoteness of the study area, data collection methods were influenced by constraints concerning feasibility in terms of security, cost, timing, and access. As mentioned in Section 4.4.3, data was collected from various sources including interviews and focus groups with key Burkinabé stakeholders and international regulatory experts, as well as information collected

during field trips to Burkina Faso and project management activities within the Target Malaria project.

Field trips served to gain first-hand information on the ground. This was mainly achieved via face-to-face interviews with key stakeholders and was rounded off with focus group discussions and archival research on local documents.

The geographical and cultural distance between the interviewer and the interviewees made it quite difficult to approach the majority of stakeholders directly. For this reason, the network of contacts of the local team was a key success factor for establishing the first contacts on the ground and to define the first set of interviewees.

Face-to-face interviews proved to be the most valuable data collection method. Whenever possible, stakeholders were first approached informally in order to create rapport, a very important aspect of the Burkinabé culture. These interactions were not formally recorded and did not yield much directly relevant information, but were a key success factor in establishing an initial bond with the respective interviewee and in introducing the purpose of the PhD study. Additionally, findings from these informal meetings helped shape the interview guidelines used in the formal interviews.

In a second step, the list of identified stakeholders was enlarged through snowballing. The process was extended until the author felt that a saturation point in data collection and analysis was reached. This was based on the guidance by Lincoln and Guba who state that the sample should be “expanded until redundancy with respect to information is reached” (Lincoln and Guba, 1985). Hence the sample size was kept open during the research process, rather than being determined upfront.

Data was collected in stages from April 2013 to May 2016. The author travelled to Burkina Faso six times during this period to collect and validate the data. She also met the Burkinabé team during workshops in Canada, Uganda, and England to discuss this data, emerging findings and their implications. Most of the formal interviews in Burkina Faso were performed between April and May 2015 in the

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following locations: Ouagadougou (incl. outskirts), Bobo-Dioulasso, several locations and villages in Hauts-Bassins region (incl. Bana Village, Souroukoudingan Village, and VK7 Village). The villages in the Hauts-Bassins region are used for entomological studies by the local project team.

Geographical reach of stakeholder	Involvement of stakeholder in health system	Cluster	Number of stakeholders interviewed per cluster
Local	User	LU/RU	40 (12 in 1:1 interviews and 28 in focus groups)
Local	Technical	LT/LM/RT	3
Local	Managerial	LT/LM/RT	1
Regional	User	LU/RU	2
Regional	Technical	LT/LM/RT	1
Regional	Managerial	RM/RP	5
Regional	Policy Maker	RM/RP	n.a.
National	User	NU/IU	2
National	Technical	NT/NM	5
National	Managerial	NT/NM	5
National	Policy Maker	NP	3
International	User	NU/IU	1
International	Managerial	IM/IP	2
International	Policy Maker	IM/IP	2
TOTAL			72

Table 2: Breakdown of interviews based on stakeholder characteristics

Note: Burkina Faso-based interviewees only.

In total, the author conducted 42 in-depth semi-structured interviews and 3 semi-structured focus groups, leading to a total of 74 people being formally interviewed. Out of these, 72 people were interviewed in Burkina Faso (in local language with a translator, in French or in English, based on the respective stakeholder's language fluency) as well as one in the UK and one in the USA (both in English). At least one person per stakeholder cluster was interviewed (Table 2).

To initiate the interview process in Burkina Faso, each participant was contacted by phone by one of the local team members involved in the project. Upon arrival at the site of the meeting, participants in the study were provided with an informed consent form, including an information sheet which stated all the details regarding their participation in the study and a certificate of consent. The fact that the participation was voluntary and included the right to withdraw from the study at any moment, without giving any reason and without it having any effect on the legal rights of the participant, was made very clear during the informed consent process. Participants were only included in the study after they gave their informed consent. Based on the stakeholder cluster and type, some of this preliminary information exchange was performed by a local team member in order not to put the interviewees under pressure. The further steps undertaken to comply with the basic principles of research ethics are detailed in Section 4.5.

Separate consent to voice-record each interview was sought. Anonymity was ensured by assigning a participant's ID code to every interviewee. For the purpose of guiding the collection process as well as to prevent data loss issues, the most important themes emerging from the interviews were also recorded on paper. Each recording was transcribed verbatim and all the data was stored in a secure database and regularly backed up in order to safeguard against potential loss of data.

Every interview started with rather broad, general questions that were similar for all stakeholder clusters (Figure 9), before asking more specific questions pertinent to the specific knowledge of the interviewee. All semi-structured interviews were digitally recorded and transcribed verbatim in order to be subsequently coded (see Section 4.4.9).

Focus groups involved a subset of stakeholders, who were questioned about their respective perceptions, opinions and beliefs. This data collection method was mainly used at community level to understand how the communities perceive the introduction and adoption process of various health and related technologies. Thus, these findings complemented the information gathered during the one-on-one interviews. Like the interviews, the focus groups were semi-structured and followed the interview guidelines for the specific stakeholder cluster (see Section o). This exercise was especially beneficial in identifying whether there are hidden barriers based on different cultural interpretations.

The data collected from the interviews and focus groups was complemented by additional archive and desktop research of public and non-public information on the health systems of Burkina Faso. Given the lack of digitalisation of most official governmental documents, these data points could generally only be obtained during the field trips.

Interviews with international regulatory experts with specific exposure to the Burkinabé regulatory system were conducted in order to gain a deeper understanding of their stances on the deployment of GM innovations in Burkina Faso. Similarly to the interviews conducted during the field trips in Africa, these interviews were also semi-structured, but followed a more stringent guideline as they focused on the interviewees' perception of key enablers and barriers to the specific adoption process during specific product development stages of GM technologies in Burkina Faso. These interviews were recorded and transcribed.

In addition to findings from field trips and interviews, data collected from the project management activities within the Target Malaria project constituted the fourth main pillar of information. Data was extracted from:

- Participation by the author in project team meetings, where information concerning the deployment strategy of the project was discussed;
- The active support of the in-country project management, especially on their outreach activities;

- The involvement of recurring working groups conference calls in each of the project modules (e.g. research planning for product development, capacity building in the African countries, regulatory pathways, risk assessment and management, communications strategies, and stakeholder engagement).

Minutes and notes from all these activities therefore provided additional insights into the barriers and enablers experienced and forecasted by the project, during the initial stages of adoption of the GM technology.

All this information was then coded, triangulated and analysed (see Section 4.4.9) and later used to develop the qualitative SD model (see Section 4.4.10).

4.4.9 Analysis and coding of the primary research data

A formal analysis of the verbatim transcriptions from the formal semi-structured interviews, focus groups, and interviews with regulatory experts was performed to extrapolate the emerging themes.

The data was analysed using a simplified version of the coding scheme of Strauss and Corbin (Strauss, 1987, Corbin and Strauss, 2008) in order to cluster the obtained information in a sensible way. The first step comprised ‘open coding’ (Glaser and Strauss, 1967), where a set of different, preliminary codes were identified (‘conceptualized’) in order to structure the perception of the interviewees in a clearer way. The data was also grouped in accordance to the main levers of the holistic framework by Atun et al. (i.e. problem, innovation, adoption system, health system, broad context, GM mosquitoes). Subsequently these codes were further aggregated into broader categories (‘categorized’) (Figure 28) with the aim of deducting generally applicable statements (Gioia et al., 2012, Strauss, 1987). In a next step the coded data was arranged next to each other in order to achieve a higher visual comparability. Thus it was possible to identify similarities and relate the codes to each other (‘axial coding’) (Locke, 1996).

After this comparative analysis, the analysed data was subjected to additional triangulation by comparing it with the additional internal and external data sources acquired during the field trips and the Target Malaria project management activities, in order to complement the findings of the interview analysis (Wrona, 2005).

The approach was used iteratively in order to continuously expand the code tables and the themes that emerged from it. Nvivo 10 was used as coding software.

4.4.10 Qualitative system dynamics modelling

There is no easy approach to the evaluation of complex health interventions and their adoption on the ground (Drummond et al., 2007). Compared to many drugs or other more standardised technologies, the analysis of complex innovations is precisely about describing their diversity and flexibility and there is no ready-made methodology available (Drummond et al., 2007). Furthermore, given our limited ability to deal with complexity (Sterman, 1994, Brehmer, 1987), it is even more important to find the most fitting evaluation method to successfully address the research question.

Various kinds of modelling techniques have proven very effective for the analysis of complexity in decision making and organizational behaviours, given the diversity present in complex interventions (Oliveira, 2014). These techniques take into account the degree to which contextual factors can affect outcomes and lead to multiple outcomes, both within as well as outside systems such as healthcare (Jun et al., 1999, Guenal and Pidd, 2010). They also take into account the interconnectedness and relationships between components of the system (Craig et al., 2008, Shepperd et al., 2009). Delays, feedback and non-linearities that influence the dynamics of the system can be included in these models (Sterman, 2000). In doing so they allow for better understanding of possible counter-intuitive behaviour and unintended consequences of interventions in systems (Oliveira, 2014, Sterman, 2000). Furthermore, they enable different scales of implementation, timeframes and choice of comparators at different organisational levels. This is especially

important in the uptake of complex technologies, when there is uncertainty on how these choices and different steps affect the final result (Oliveira, 2014).

All these deliberations had already been reflected in the choice of framework for the data collection, but were also crucial for the choice of data analysis method. For this purpose, the author used systems thinking and the emerging codes and themes from the primary research data (i.e. semi-structured interviews) to create a qualitative SD model with the principle goal of understanding the behaviour of the system and the key factors influencing the development and adoption of GM mosquitoes in Burkina Faso.

Following the analytical regime proposed by Azoulay et al. (2010) the author first explored the codes and nodes derived from the analysis of the primary data (i.e. interviews and focus groups) and categorised and structured the data according to these concepts and themes (see Chapter 9). In a second phase, qualitative system dynamics modelling and more specifically the causal loop diagram method (Azoulay et al., 2010, Sterman, 2000) were used to analyse the relationships within those emerging themes and to generate an explanation of the identified dynamics.

The qualitative system dynamics model was drafted based on a five-step modification of the process suggested by John Sterman (Sterman, 2000): problem articulation, formulation of dynamic hypothesis, formulation of a qualitative SD model, validation, and policy design. The methodology underlying the development of the SD model, along with additional insights on qualitative system dynamics modelling, are detailed in Chapter 9 of this PhD thesis. Given the limited previous exposure to SD modelling, the author attended a system dynamics course at the MIT Sloan School of Management (Cambridge, MA) over the winter semester 2015/16 in order to gain first-hand experience in modelling complex systems before starting the modelling process for this PhD study.

4.5 Research ethics

Throughout the study, the author strictly adhered to the basic principles of research ethics, including minimising the risk of harm, obtaining informed consent, protecting anonymity and confidentiality, avoiding deceptive practices, and providing the right to withdraw at any time (Lærd, 2012).

In order to ensure compliance to those principles, and follow Target Malaria's ethical policy requirements, ethical clearance by the Imperial College Research Ethics Committee (ICREC) was received for all the procedures and protocols for the collection and analysis of the qualitative research data for this PhD study. The ICREC approval (ICREC reference: 15IC2634) can be found in the Appendix (Section 12.1).

The Burkinabé team had also received approval via their own Institutional Research Ethics Committee in order to cover also the work performed in this study.

Ethical review summary

The work for which the ethical approval was sought involved interviews and focus groups composed of a number of local and international stakeholders. These participants were selected to gain a better understanding and knowledge of local health system, context, and regulatory system, as well as of the key factors to the adoption of a complex health technology in Burkina Faso.

The following statements are true for the entire context of this study:

- The research involved the use of existing data, documents or records which were fully anonymised so that participants cannot be identified in any way;
- The research involved the use of interview procedures or observations of public behaviour where participants cannot be identified in any way, and where they are at no risk of adverse treatment through participation (e.g. criminal investigation);
- All the participants were over 18 years of age and the study did not involve vulnerable groups;

- The research has no controversial ethical aspects.

As per Imperial College regulations, the PhD study has been independently peer reviewed by the Progress Panel Review members 9 and 18 months after the start of the PhD.

Recruitment process and informed consent

The data collection process laid out in Section 4.4.8 followed clear ethical rules and principles outlined by the World Health Organization Research Ethics Review Committee (WHO ERC) Guidelines on The Process of Seeking Informed Consent (WHO ERC).

As part of the process a tailored informed consent form including an information sheet and a certificate of consent have been produced based on the WHO ERC Informed Consent Form Template for Qualitative Studies (WHO ERC) (see Section 12.3 in the Appendix).

The information sheet stated all the details regarding the participation of volunteers in the study. These included: introduction to the study, purpose of the research, participant selection, procedures, duration of the interview, voluntary participation and right to refuse or withdraw, benefits and reimbursements, confidentiality, sharing of the results, ethical approval, as well as contact details. This document was read to the participants prior to the beginning of the interviews and focus group, all the arising questions were answered in relation to it and a written copy was handed over for their records.

The certificate of consent summarised the major points discussed in the first section (information sheet) and entailed the signature of the participants as well as of the researcher. This is in duplicate copy: one for the participant and one for the researcher. As per local use, for illiterate people and those who requested it, the statements were tape recorded and oral consent was given.

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Participants were only included in the study after they gave their informed consent and it was ensured that everyone treated with respect at any given time.

Given the language barriers faced by certain stakeholders, the informed consent form was also translated into French, the official governmental language in Burkina Faso. Furthermore, when needed, a professional translator providing translation from English or French to the local native language and vice versa was present to support the research team. The translator was also bound to a confidentiality agreement in order to ensure anonymity of the participants.

Withdrawal and benefits

Throughout the process it was a priority of the author to ensure that the fact the participation was voluntary and included the right to withdraw from the study in any moment without giving any reason and without it having any effect on the legal rights of the participant was understood by the participants.

Participants were not provided any incentive and reimbursements to take part in the research. In all the cases, the research team travelled to the participants' work or home locations to meet them, so no travel expenses were reimbursed. Nevertheless, given the very hot climatic conditions during the in-country interviews and focus groups the research team, if deemed necessary, bought refreshments (water or other soft drinks only) for the participants in order to ensure their wellbeing.

Confidentiality

Confidentiality was granted by anonymising all the information.

Every participant received a unique ID code based on the following system:
CC-LC-ST-NNN-SS

- CC= country code (e.g. BF for Burkina Faso);
- LC= location code (e.g. BD for Bobo-Dioulasso);
- ST= stakeholder type (based on the matrix mentioned in 4.a. – e.g. UL= user local);
- NNN= last 3 letters of name;
- SS= first 2 letters of surname;

The Excel file with the participant's ID codes was kept strictly confidential (password protected) and only the principal investigator and the author of this PhD thesis had access to it. No copies were made.

The meetings were all voice recorded, but no-one was identified by name on the recording. The recordings were kept in a folder with restricted access only to the principal investigator and the author. All the recordings were then transcribed and the anonymised transcripts were analysed exclusively by the author and the principal investigator. No one outside the research team had access to the transcripts, which were also stored in a safe folder with restricted access. The information recorded and transcribed was treated as confidential.

Further ethics trainings

The econometric analysis was performed on a DHS dataset survey containing data collected through personal interviews with study respondents. In order to fully understand the rights of these study participants as well as the required study procedures, a CITI Program Human Subjects Training for social and behavioural research investigators, covering the following aspects, was successfully completed:

- Belmont Report and CITI Course Introduction (ID: 1127)
- History and Ethical Principles - SBE (ID: 490)
- Defining Research with Human Subjects - SBE (ID: 491)
- The Federal Regulations - SBE (ID: 502)
- Assessing Risk - SBE (ID: 503)
- Informed Consent - SBE (ID: 504)
- Privacy and Confidentiality - SBE (ID: 505)
- Students in Research (ID: 1321)
- Conflicts of Interest in Research Involving Human Subjects (ID: 488)
- Research with Prisoners - SBE (ID: 506)
- Research with Children - SBE (ID: 507)
- International Research - SBE (ID: 509)
- Vulnerable Subjects - Research Involving Workers/Employees (ID: 483)

The complete CITI Training course completion report can be found in the Appendix (Section 12.2).

5 Innovation in malaria eradication and GM technologies

This chapter introduces to the reader the burden of malaria and the efforts undertaken so far to eradicate this curable and preventable disease which still places half of the world's population at risk. It then looks at the historic development of malaria elimination tools and the adoption of the most relevant technologies, through a systematic literature review. This was carried out in order to gain an overview of the key factors leading to and hindering the general adoption of malaria elimination technologies, to better understand the possible influences on the adoption of GM mosquitoes in Burkina Faso.

Given that GM technology has a specific history and its safety is still much debated, the author deemed it necessary to carry out another systematic literature review on the research on adoption of GM technologies, to complement an overview of the development of GM technologies.

Systematic literature review on the adoption of malaria and GM interventions

After a review of the literature on adoption of innovation in general and within health systems in particular (see Chapter 2), the author performed systematic literature reviews of key enablers and barriers to the adoption of malaria eradication innovations and GM technologies in general.

From general reviews of both innovation types, the author identified key interventions within those areas. Within the malaria technologies, Long Lasting Insecticide Treated Nets (LLINs), Rapid Diagnostic Tests (RDTs), Intermittent Preventative Treatment (IPT) were selected for review. For GM technologies the most significant interventions were less definite, but Bt cotton, Golden Rice, GM vaccines, and Oxitec's GM mosquitoes were chosen for the purpose of the review.

The systematic reviews draw on the work partially conducted by Mr Thomas Lau, who performed his final year project (A systematic review of the key factors for the adoption and diffusion of malaria and GM innovations. What can we learn for the

potential future release of GM mosquitoes against malaria?) under the supervision of the author and of Prof Crisanti.

To identify relevant studies, the research was conducted using PubMed, Web of Science and Google Scholar and the following search strings were taken:

- Adoption or diffusion or uptake and malaria and the key malaria intervention names (LLINs / RDT / IPT);
- Adoption or diffusion or uptake and GM or genetic modification and the key intervention names (Bt cotton / Bt cotton / Golden Rice / GM vaccines / Oxitec GM mosquitoes).

The combined searches yielded 267 papers that seemed relevant at first glance. The results were then narrowed down by screening the title of each article and subsequently the abstracts of the papers. The relevance and quality of the content of the articles was also used as selection criteria. The selection process led to the identification of approximately 70 articles, precisely:

- 9 papers for LLINs;
- 9 papers for RTDs;
- 10 papers for IPT;
- 26 papers for Bt cotton;
- 8 papers for GM vaccines;
- 6 papers for Golden Rice;
- 4 papers for Oxitec GM mosquitoes.

5.1 Malaria

Malaria is a life-threatening vector-borne infectious disease caused by parasites of the genus *Plasmodium* that are transmitted to people through the bites of infected female mosquitoes of the genus *Anopheles* (Winzeler, 2008, CDC Centers for Disease Control and Prevention, 2015a). World-wide there are approximately 3,500 species of mosquitoes grouped into 41 genera (CDC Centers for Disease Control and Prevention, 2015a, Hay et al., 2010), but only a handful, approximately 30-40, which all belong to the *Anopheles* genus, can transmit the parasite (i.e. are 'vectors') which causes human malaria (Tuteja, 2007, Kiszewski et al., 2004). These represent roughly 1% of the entire mosquito population but have dramatic effects on the human population.

Humans infected with *Plasmodium* parasites may present a wide variety of symptoms, ranging from almost absent or very mild symptoms to severe disease and even death (CDC Centers for Disease Control and Prevention, 2016b). Hence, the disease can be categorised as uncomplicated or severe (complicated) (CDC Centers for Disease Control and Prevention, 2016b). In most cases, infected subjects often experience flu-like signs and symptoms like fever, headache, sweats and shivering which can often resemble other conditions such as gastroenteritis and viral diseases (Nadjm and Behrens, 2012, CDC Centers for Disease Control and Prevention, 2016b). If diagnosed and treated promptly and correctly malaria is a curable disease (CDC Centers for Disease Control and Prevention, 2016b).

Nevertheless, if left untreated or unrecognised the disease tends to evolve and patients develop more debilitating symptoms like joint pain, vomiting, elevated temperature, mild jaundice, enlargement of the liver, increased respiratory rate, perspiration as well as convulsions (CDC Centers for Disease Control and Prevention, 2016b). In severe cases impairment of consciousness, seizures, coma, neurologic abnormalities, acute kidney failure and haemolysis often lead to death (CDC Centers for Disease Control and Prevention, 2016b).

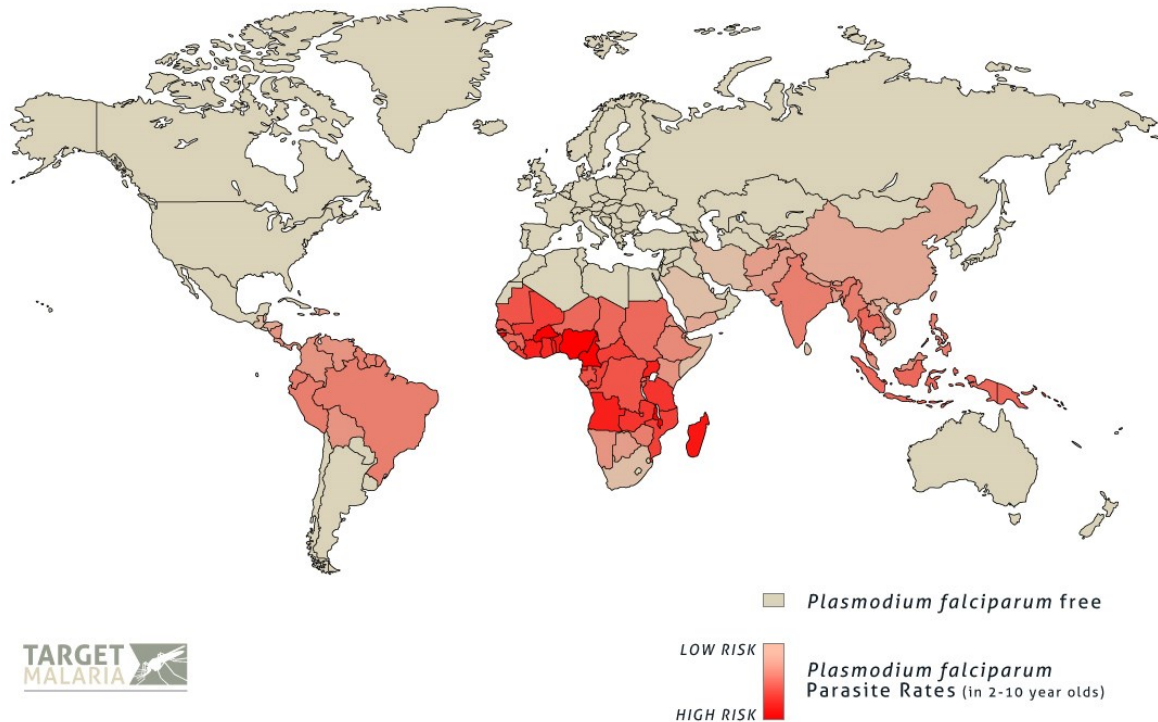


Figure 10: Global distribution of malaria.

Sources: Target Malaria (2016d), Gething et al. (2011)

According to the WHO about half the world's population – an estimated 3.2 billion people – are still at risk of contracting malaria (WHO, 2015b). In 2015 alone, 214 million new malaria cases were estimated (uncertainty range varying between 149 million and 303 million), which led to approximately 438,000 malaria deaths (with an uncertainty range of 236,000 to 635,000) (WHO, 2015b). The overwhelming concentration of malaria cases and deaths remains in Africa, with more than 90% of the world's malaria deaths occurring on that continent (Bremner et al., 2001), followed by the South-East Asia Region (7%) and the Eastern Mediterranean Region (2%) (WHO, 2015b, Roll Back Malaria, 2015) (Figure 1). Children under five years of age and pregnant women are the most severely affected (WHO, 2012b) – in 2015 306,000 children lost their life to this preventable disease, translating into a young life (<5 yrs.) lost to malaria every two minutes (Target Malaria, 2016d, WHO, 2015b, Roll Back Malaria, 2015).

Not only is malaria a leading killer, but it also results in enormous developmental burdens and is a major barrier to economic progress (Sachs and Malaney, 2002),

especially in the developing world. The disease has an impact in many aspects of life including fertility, population growth, saving and investment, worker productivity, absenteeism, premature mortality and medical costs (Sachs and Malaney, 2002). According to the Roll Back Malaria Partnership, the direct economic cost of malaria in 2015 for the African continent was of USD 12 billion (Roll Back Malaria, 2015), which translates in a 1.3% loss of GDP growth per year for Africa (Roll Back Malaria, 2015).

Given the huge impact the disease has on the human population, combating malaria was identified as one of the Millennium Development Goals (MDG 6C) (WHO, 2010) and over the past decade international disbursements for malaria control have increased steeply from less than USD 100 million in 2000 (WHO, 2012b) to an approximately USD 960 million in 2005 and to roughly USD 2.5 billion in 2014 (WHO, 2015b). In fact, this led to great achievements in the fight against malaria. Between 2000 and 2015 mortality rates caused by malaria have fallen by 66% amongst all age groups, and by 71% among children under five (WHO, 2015b), in line with target 6C set by the World Health Assembly. This progress was mainly achieved possible through the rollout of effective prevention and treatment tools with artemisinin-based combination therapies, insecticide-treated bednets and indoor residual spraying playing a key role in this progress (Murray et al., 2012, WHO, 2015b).

Nevertheless, despite the ever increasing efforts undertaken, the improvement curve is levelling off (WHO, 2013c) and millions of people continue to lack access to preventive therapies, diagnostic testing and quality-assured treatment (WHO, 2015b). Additionally, mosquitoes are slowly becoming resistant to insecticides and are even finding ways to avoid bednets while the parasites are becoming resistant to available medications (WHO, 2015b). Furthermore, current interventions are expensive to maintain and only protect people under certain circumstances. For example, malaria prevention drugs are not recommended for long term use in disease endemic countries, and bednets only provide shelter from mosquitoes at night and not necessarily during dawn and dusk which are the major biting times of *Anopheles* mosquitoes (Target Malaria, 2016d).

Unfortunately, though, these challenges associated with availability of interventions and technology which are leading to stagnation in improvement levels, are not the only ones faced in malaria eradication. There are emerging economic challenges as the demand for funds required to fight the disease using existing approaches are predicted to rise exponentially (Target Malaria, 2016d). In fact, the WHO and Roll Back Malaria estimate there will be a need to mobilise USD 6.4 billion per year by 2020 (Roll Back Malaria, 2015) and USD 8.7 billion per year by 2030 in order to achieve the 90% reduction goal by 2030 set in the 'Global Technical Strategy for Malaria 2016–2030' (WHO, 2015b, WHO, 2015a), adopted by the World Health Assembly in May 2015. This must be compared to the USD 2.7 billion currently available – less than half of what is needed (Roll Back Malaria, 2015).

Hence, despite the progress achieved in tackling the health and economic burden of malaria, the international community has reached the consensus that a new and cost-effective technological innovation is needed to overcome limitations of the available prevention methods to finally eliminate malaria.

5.1.1 The fight against malaria

When speaking about the fight against malaria it is important to define the differences between control, elimination, and eradication. These are often wrongly used as synonyms, but the WHO clearly defines them as different levels of achievement of the same goal:

- Malaria control: “the reduction of the malaria disease burden to a level at which it is no longer a public health problem” (WHO, 2013c).
- Malaria elimination: “the reduction to zero of the incidence of infection caused by human malaria parasites in a defined geographical area as a result of deliberate efforts. Continued measures to prevent re-establishment of transmission are required” (WHO, 2013c).
- Certification of malaria-free status: “the official recognition of malaria-free status granted by WHO after it has been proven beyond reasonable doubt that the chain of local human malaria transmission by *Anopheles*

mosquitoes has been fully interrupted in an entire country for at least 3 consecutive years” (WHO, 2013c).

- Malaria eradication: “permanent reduction to zero of the worldwide incidence of infection caused by a particular malaria parasite species. Intervention measures are no longer needed once eradication has been achieved” (WHO, 2013c).

5.1.2 Innovations in the fight against malaria

As mentioned in Section 5.1 the rollout of effective prevention and treatment tools such as artemisinin-based combination therapies, insecticide-treated bednets and indoor residual spraying has played a crucial role in the fight against malaria in the last 15 years (Murray et al., 2012, WHO, 2015b). Nevertheless, malaria (or a resembling disease) has been known for more than 4,000 years (CDC Centers for Disease Control and Prevention, 2016a), and the fight against malaria has a long history of technological innovation in its diagnosis, prevention and treatment.

Despite the fact that the symptoms of what would later be named malaria were already described in ancient Chinese medical writings, the *Nei Ching* (The Canon of Medicine) around 2700 BC, the first anti-fever properties of qinghao, whose active ingredient is nowadays known as artemisinin, were first described only in 340 AD by Ge Hong of the East Yin Dynasty (CDC Centers for Disease Control and Prevention, 2016a). Subsequently, but only in the early 17th Century, the Spanish Jesuit missionaries discovered from aboriginal Indian tribes of a medicinal bark used for the treatment of fevers (CDC Centers for Disease Control and Prevention, 2016a). The medicine distilled from the bark is now known today as the antimalarial, quinine (CDC Centers for Disease Control and Prevention, 2016a). In fact, artemisinins and quinine are still the most effective antimalarial drugs currently available (CDC Centers for Disease Control and Prevention, 2016a).

The malaria parasite was only discovered on November 6th, 1880 by Charles Louis Alphonse Laveran, a French army surgeon stationed Algeria, who was the first to notice parasites in the blood of a patient suffering from malaria (CDC Centers for

Disease Control and Prevention, 2016a). For his discovery the French surgeon was awarded the Nobel Prize in 1907 (CDC Centers for Disease Control and Prevention, 2016a).

In the years to follow a series of further findings led to a better understanding of the parasite: in 1886 Camillo Golgi, an Italian neurophysiologist, established the differentiation of the malaria species, while between 1890 and 1922 various investigators differentiated and named all the different *Plasmodium* species affecting humans and animals (CDC Centers for Disease Control and Prevention, 2016a).

The discovery 1897 that mosquitoes transmit malaria parasites was another milestone in the fight against malaria is attributed to Sir Ronald Ross, a British officer in the Indian Medical Service (CDC Centers for Disease Control and Prevention, 2016a). He demonstrated that *Plasmodium* could be transmitted from infected patients to mosquitoes and back to birds after a sporogonic cycle (the time interval during which the parasite developed in the mosquito) (CDC Centers for Disease Control and Prevention, 2016a). This discovery was also awarded with the Nobel Prize in 1902 (CDC Centers for Disease Control and Prevention, 2016a). The proof that mosquitoes were also able to transmit back to humans was done by a team of Italian investigators in London in 1899 (CDC Centers for Disease Control and Prevention, 2016a).

The first official antimalarial drug was finally discovered in 1934 by a German scientist in the labs of Bayer I.G. Farbenindustrie A.G. and was finally acknowledged and established as an effective and safe antimalarial drug in 1946 (CDC Centers for Disease Control and Prevention, 2016a).

The insecticidal properties of dichloro-diphenyl-trichloroethane (DDT) were identified in 1939 (CDC Centers for Disease Control and Prevention, 2016a). The insecticide was then widely used for malaria control in southern Europe and North America at the end of WWII, after it had proven effective against malaria-carrying mosquitoes by British, Italian, and American scientists (CDC Centers for Disease Control and Prevention, 2016a). The use of DDT together with the drainage of swamps was the key to malaria eradication in those two areas (CDC Centers for

Disease Control and Prevention, 2016a). Nevertheless, in 1972 DDT use was banned in the USA by the US Environmental Protection Agency (EPA) due to its adverse effects on health and environment (US Environmental Protection Agency (EPA), 2016).

The Malaria Eradication Programme between 1955 and 1969, which contributed to a significant reduction of the malaria burden in Asia and Latin America, was focused on the use of indoor residual spraying (IRS) (World health Organisation (WHO), 2006). This technology is based on spraying long-acting chemical insecticides on the walls and roofs of households in order to kill the adult vector mosquitoes that land and rest on these surfaces and was first endorsed by the WHO in 1950 (World health Organisation (WHO), 2006).

In the 1970s, Chinese scientists re-discovered artemisinin (qinghaosu), which was extracted from the traditional Chinese medical drug qinghao, from their ancient remedies and commercialised it (Li and Wu, 1998, Hsu, 2006, Cui and Su, 2009). The origins of this scientific re-discovery are unclear and disputed (Li and Wu, 1998, Hsu, 2006, Cui and Su, 2009), but nevertheless, artemisinin and artemisinin-based combination therapies (ACTs), which were introduced in 1990, are one of the most predominant drugs contributing to the reductions in malaria cases in sub-Saharan Africa and are considered a key tool for malaria eradication (WHO, 2015b).

While bednets had been used for many decades to shield humans from mosquitoes, the idea of combining the effect of pyrethroid insecticides and bednets for integrated vector control was first endorsed by the WHO in its 1983 technical report on 'Integrated Vector Control' and its efficacy proven in 1985 (Schreck and Self, 1985). Since then, insecticide treated nets (ITNs) have been introduced as one of the major strategies for malaria control in the global agenda and have seen a series of technological evolutions which have led to the development of the new-generation of long lasting insecticide treated nets (LLINs).

In terms of diagnosis of malaria one of the biggest breakthroughs was the development of rapid diagnostic test (RDTs) for the detection of the malaria parasites (antigens) in human blood (WHO, 2016c). Unlike other malaria detection methods, RDTs allow for a much more a rapid and accurate diagnosis, especially in

remote areas with limited access to good quality microscopy services (WHO, 2016c). This technology was first endorsed by the WHO in 1999 in the joint WHO and USAID informal consultation report 'New Perspectives on Malaria Diagnosis' (WHO, 2000a).

Lastly, an extensive research beginning in the 1960s on potential malaria vaccines has finally led to the approval of GlaxoSmithKline's 'RTS,S' by the Europe's Committee for Medicinal Products for Human Use (CHMP) in June 2015 (Technical Expert Group on Malaria Vaccines (JTEG) and WHO Secretariat, 2015). Nevertheless, the efficacy of this vaccine is still fairly low compared to the one of conventional commercial vaccines for other diseases, and hence its deployment is still strongly debated. However, in November 2016, the WHO announced that funding for the first phase of the vaccine pilots (2017-2021) had been secured and that vaccinations would begin in 2018 through pilot projects in three sub-Saharan African countries (WHO, 2016d).

Despite the long list of technological advancements in malaria detection, prevention, and treatment, progress towards eradication seems to be levelling-off and the international community has reached the consensus that new and cost-effective technological innovation is needed to overcome limitations of the available methods.

5.1.3 Vector control and GM mosquitoes as innovative technology for malaria eradication

As described in Section 5.1, there are approximately 3,500 species of mosquitoes world-wide, but only a relatively small number (ca. 30-40 species) can transmit the parasite which causes malaria (Tuteja, 2007, Kiszewski et al., 2004). This means that new technologies, aimed at eliminating those specific insects that function as a vector for the parasite, could have a great impact in the fight against malaria.

In the past, vector control has proven to be a powerful tool against vector-borne diseases (Takken and Knols, 2009), with chemical control measures and environmental management playing a key role (Takken and Knols, 2009). In the

1960s the widespread use of DDT against mosquitoes - combined with the use of antimalarial drugs to eliminate the parasite in humans and the drainage of larval habitats - have led to the eradication of the disease in most of the developed countries (e.g. in Europe and North America) (Trigg and Kondrachine, 1998).

Nevertheless, at present, in low and middle-income countries sub-optimal distribution and adoption of insecticide-treated nets (ITNs) (WHO, 2013c), poor indoor residual spraying (IRS), insecticide resistance (Takken and Knols, 2009), and resistance of the parasite to medications are persistent and the success rates in the combat against malaria do not provide benefits commensurate with the efforts undertaken (WHO, 2013c). This has put the need for a new innovative technology in the spotlight. Additionally, it has become clear that for the alternative solution to become a valuable tool for malaria eradication it will need to provide area-wide, durable, and low-cost protection to malaria (Windbichler et al., 2011).

The recent advances in the discovery of the genome sequences of *Anopheles* mosquitoes (Holt et al., 2002) and of the *Plasmodium* parasites (Gardner et al., 2002) offer new possibilities for vector control technologies based on genetic applications and transgenic technologies. Therefore, genetic methods to manipulate the specific vectors to hinder parasite transmission to humans or to eradicate disease-carrying vectors populations have been discussed as attractive alternative control measures (Windbichler et al., 2011, Catteruccia et al., 2000, Nolan et al., 2011). The potential advantages of these specific methods involving GM mosquitoes are increased effectiveness, species specificity (Windbichler et al., 2011) and no need to change human habits.

Given that most of these technologies are still in laboratory research phase, the translation of these technologies into real control measures initially requires the genetic modification to spread from laboratory mosquitoes to field populations (Sinkins and Gould, 2006). Once this technological tool is validated, it will be essential to have a health system that is ready for the acceptance of such an innovative approach, as well as a logistics network capable of delivering the technology on a broad geographical scale. Therefore, for these technologies to translate into effective control methods and for them to be efficiently implemented

and scaled up, a coordinated activity between different actors will need to take place in advance of deployment.

In order to understand which factors will be important for the adoption of GM mosquitoes the author decided to perform systematic literature reviews of the enablers and barriers for the adoption and diffusion of key malaria innovations and key GM innovations. The findings are reported in Section 5.2 and 5.4.

5.2 Systematic review: key factors for the adoption and diffusion of malaria innovations

Section 5.1.2 describes the most important historical malaria intervention discoveries. Based on a general review of malaria control, LLINs and IPT were selected as key malaria prevention methods while RDTs was chosen as main malaria diagnosis innovation within the last decade. These are all considered key interventions by the WHO and shape the context for the introduction of GM mosquitoes (WHO, 2015b). Hence, the systematic literature review of malaria innovations was focused on the barriers and enablers which have led to an effective adoption of these specific interventions.

5.2.1 Long Lasting Insecticide Treated Nets (LLITNs)

In a number of countries, bednets are the primary malaria prevention tool (President's Malaria Initiative, 2014e, President's Malaria Initiative, 2014d, President's Malaria Initiative, 2014b, President's Malaria Initiative, 2014a). The net provides its user with a physical barrier against mosquitoes, preventing bites and the contraction of malaria (CDC Centers for Disease Control and Prevention, 2015b). The advantages of adopting this type of intervention have been demonstrated through trials in various malaria endemic countries. In regions where high levels of community adoption are achieved, entire community have been sustainably been protected (Hawley et al., 2003).

Different types of bednets are currently in use; those models which had been treated with insecticide are considered to be most effective. Pyrethroid is the only insecticide approved for bednet use (CDC Centers for Disease Control and Prevention, 2015b). Advances in technology have allowed for the development of insecticide treated bednets, which have proven to be more sustainable and cost-effective in comparison to conventional insecticide treated. These are now considered as a key malaria intervention (CDC Centers for Disease Control and Prevention, 2015b). Figure 11 indicates the growth in the use of insecticide treated bednets from 2000-2013 in sub-Saharan Africa. Over time this has helped to reduce the overall mortality rate of children under 5 by 20% (Figure 11) (CDC Centers for Disease Control and Prevention, 2015b). Around two-thirds of households now have at least one insecticide treated net and almost a third of households have sufficient nets for all members. However, Figure 11 also highlights that there still need to be efforts to increase availability of bednets to all household members.

A further problem is that the effectiveness of bednets may be declining because mosquitoes are reported to have become resistant to insecticide (GiveWell, 2015). For instance, in Ladji, Indonesia pyrethroid no longer effectively deters mosquitoes with the mosquito mortality rate dropping to only 30% in this area (N'Guessan et al., 2007).

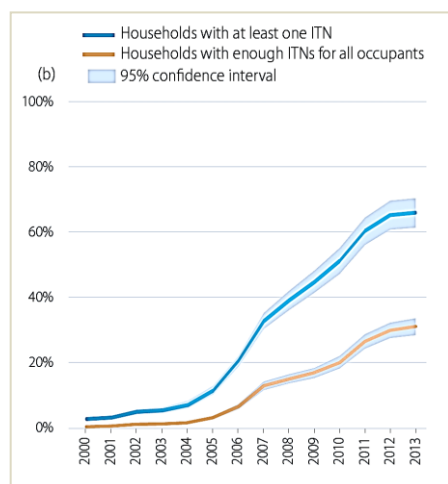


Figure 11: Rise in use of insecticide treated bednets from 2000-2013 in sub-Saharan Africa.

Source: Bhatt et al. (2015)

Barriers and enablers to the adoption of LLITNs adoption

Previous research has identified a number of barriers and enablers to achieving LLITNs coverage. In addition to theft of bednets and corruption (Bate, 2011), barriers relate to organisational, infrastructure and cultural and social factors. In a large part of sub-Saharan Africa, the quality of infrastructure is poor. The average Logistics Performance Index (LPI), an index measuring the transport-related infrastructure, is 2.3 on a scale of 5 in sub-Saharan Africa (World Bank, 2014). This impacts the supply of bednets, significantly compromising coverage in many countries (Nfl, 2008). Stock depletions are regularly experienced in some countries (President's Malaria Initiative, 2014e, Nfl, 2008), mainly due to inefficiently designed supply chains. A carefully designed supply chain can make a substantial difference in local adoption of bednets (President's Malaria Initiative, 2014d). In Kenya, the supply chain has been outsourced to the private sector, and has led to no LLITNs stock outs (President's Malaria Initiative, 2014c). Ghana achieves no stock outs by supervising the supply chain intensely (President's Malaria Initiative, 2014b).

As mentioned in Chapter 2 health systems of low-income countries, and especially of some African countries, have underdeveloped or completely lack intermediary (such as doctors and hospitals), organisational and regulatory bodies within their health systems (Bloom et al., 2009), often leading to heavily overburdened health systems (Nfl, 2008). This has been recognised as a major barrier to the adoption of LLITNs in some countries. Conversely, strong government leadership fully committed to bednet adoption and clear national strategies are seen as key enablers (President's Malaria Initiative, 2014c). These need to be coupled with the provision of high quality training and supervision, and bednet guidelines, to ensure that correct protocols are carried out (President's Malaria Initiative, 2014c, President's Malaria Initiative, 2014a).

Cultural and social barriers also play a role in affecting LLITNs adoption, although it is important to recognise the differing contexts across Africa. For example, Kenyan communities understand that malaria can be detrimental and agree with the need to obtain and use LLINs correctly (President's Malaria Initiative, 2014c). However, in

other contexts cultural and social factors can impede adoption. In food insecure communities, malnutrition is considered to be a greater challenge than malaria (Nfl, 2008); as a consequence, bednets are used for fishing in some communities (GiveWell, 2015).

Low literacy levels are also problematic – 38% of African adults are illiterate and thus cannot understand the bednet guidelines provided. As a result they struggle to use the nets correctly (Unesco, 2015, President's Malaria Initiative, 2014e). The education system has therefore been identified as a key enabler to this intervention. In schools, teachers can explain reasons why this technology is useful to young people. Furthermore, the pupils can then relay this information to household members (President's Malaria Initiative, 2014b). Schools are therefore not only useful in this respect, but they also act as an efficient distribution route. For the education system to have a positive effect close collaboration between health and education sectors is required (President's Malaria Initiative, 2014d, Lau, 2016).

Thirty-two of the world's most indebted countries are in Africa, resulting in multiple economic barriers to technology adoption (World Bank, 2016c). Willingness to pay for bednets is extremely low, hence the mass distribution of free nets is common. A study carried out in 29 regions in Africa found that an increase in the price of bednets from USD 0.00 to USD 0.75 reduced demand by 75% (GiveWell, 2015). Adoption and diffusion is therefore aided by having a well-funded health system that can cope with free bednet distribution, as well as having consistent donor support from developed countries (President's Malaria Initiative, 2014c). The Global Technical Strategy for Malaria 2016-2030, has therefore, called for a major funding increase (WHO, 2015a).

5.2.2 Rapid Diagnostic Tests (RDTs)

The WHO recommends confirmation of malaria before commencing treatment with anti-malarial drugs (Zhao et al., 2012). Rapid diagnostic tests (RDTs) allow early diagnosis, helping to reduce the number of cases of severe malaria (Figure 12) (Kyabayinze et al., 2010). Currently, numerous health centres over-prescribe anti-

malarial drugs, as presumptive diagnosis persists throughout malaria endemic countries (Zongo et al., 2016, Faust et al., 2015, Zhao et al., 2012, Kyabayinze et al., 2010). Over-prescription is leading to growing resistance, documented in the World Malaria Report 2015 (WHO, 2015b). Therefore, RDTs not only allow for more comprehensive diagnosis, but also help to combat the mounting resistance conundrum. The literature review identified key enablers and barriers of RDTs; unsurprisingly there are similarities with those found in LLINs (Lau, 2016).

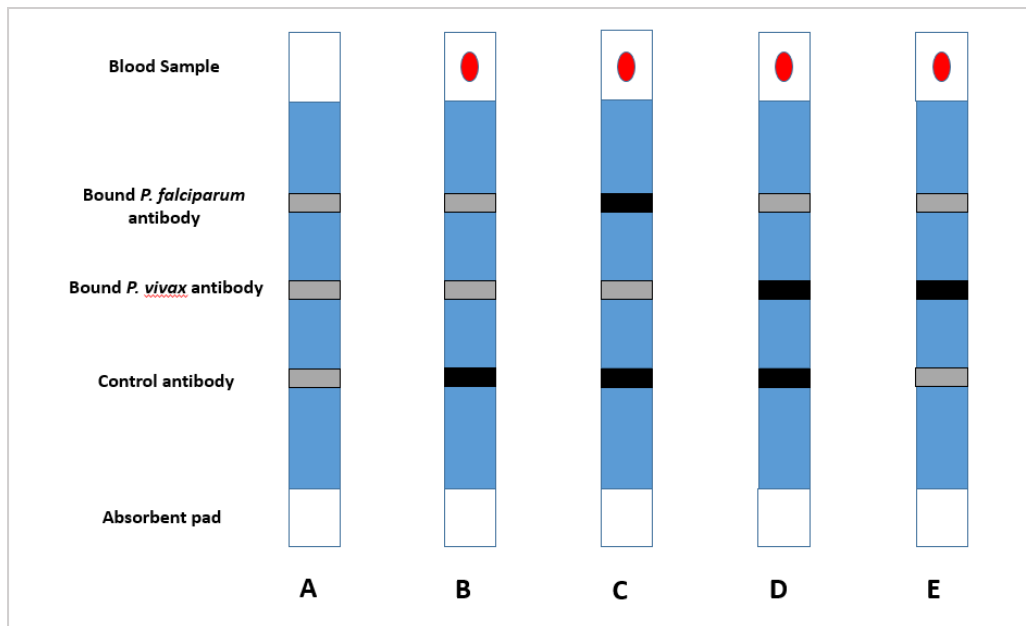


Figure 12: Rapid diagnostic test mechanism.

Test A shows a blank test, and highlights the key components of an RDT. Blood samples are placed on the RDT and results are achieved when antigens bind to different components. Test B shows a negative result as there is only control binding. Test C shows a positive result for *P. falciparum* strain of malaria as both control and *P. falciparum* antigens have bound. Test D shows a positive result for *P. vivax* malaria strain and Test E shows a negative result, as there is no control antigen to antibody binding.

Source: Lau (2016)

Barriers and enablers to the adoption of RDTs adoption

The spread of RDTs has been a slow. Again, this is the result of a combination of organisational, infrastructure, economic, and social and cultural factors. A study carried out by the Global Fund showed that efficient adoption of RDTs would occur if a set criterion was met. The criteria includes that a series of organisational changes occur at different stakeholder levels, that an efficient supply chain be

developed, that correct administration of RDTs occurs, and that there are incentives such as price subsidy as well as positive attitudes towards the technology (Zhao et al., 2012, Lau, 2016).

As noted above, infrastructure across large parts of Africa is poor. This impacts on supply chains for RDTs in a similar way to those identified in LLINs. The importance of an efficient supply chain management was shown in Burkina Faso, where inefficiencies resulted in RDT stock outs and frequent supply chain disruption, hindering RDT availability in health centres (Boadu et al., 2016, Miller and Sikes, 2015). Similar problems have been observed in Nigeria (Zongo et al., 2016, Thron and Awoleye, 2015). A lack of RDTs in health centres also decreases patient acceptance of RDTs and uptake rate (Thron and Awoleye, 2015).

A frequently observed problem is the lack of clear and updated information on RDTs and guidelines available to health providers (Zongo et al., 2016, Boadu et al., 2016, Miller and Sikes, 2015). This is possibly a reflection of poor training, evident in the inconsistent knowledge discovered between health staff (Zongo et al., 2016, Miller and Sikes, 2015). Another barrier is the lack of adherence to test results and the limited belief in test credibility (Faust et al., 2015). In Uganda, 51% of employees of primary health facilities did not believe that a negative result excluded malaria and still prescribed anti-malarial drugs (Kyabayinze et al., 2010). In Burkina Faso, anti-malarial drugs were prescribed in over 50% of negative RDT cases (Zongo et al., 2016). The importance of training and supervision in the correct administration and use of RDTs is therefore seen as essential, along with clear information and guidelines (Zongo et al., 2016). The low community faith in RDT test results, due to poor regulation, can be reinforced by the presence of low quality RDTs on the market, producing inaccurate results (Miller and Sikes, 2015).

Cultural and social beliefs also limit RDT coverage. The belief that a fever is always directly associated with malaria leads to a consumer demand for anti-malarial drugs regardless of RDT results (Miller and Sikes, 2015). Other beliefs and misconceptions have also limited RDT coverage. Some religions hold that blood is sacred, inhibiting the use of RDTs as they require a blood sample (Miller and Sikes, 2015). The fear that RDTs are testing for HIV also has a large impact. A study carried out in Ivory Coast,

resulted in only 34 of 100 patients participating in tests on the grounds that the test may detect HIV (Miller and Sikes, 2015). Cultural and social barriers to the use of RDTs can be addressed by the development of local and culturally relevant community programmes. An example was carried out in Ghana and resulted in 98% preference for RDT usage (Miller and Sikes, 2015).

Economic barriers to RDT coverage have been observed, notably an unwillingness to pay. This is related to the perception that an RDT is a test, not a treatment, and therefore it is not cost-effective for the patient (Cohen et al., 2015). In Uganda, one study showed that people were willing to pay USD 0.53 for a test, but the unsubsidised cost was USD 2.69 (Miller and Sikes, 2015). In southeast Nigeria, improved education was shown to increase the willingness to pay for RDTs (Thron and Awoleye, 2015). A successful programme in Myanmar showed that intensive information, education and counselling resulted in an overall higher RDT uptake (Aung et al., 2015). These examples really highlight the importance of education to enhance community understanding of RDTs.

Like LLINs, RDTs face some challenges associated with the level of technological development. They are susceptible to heat and humidity, which can render tests invalid and unusable. Another limiting factor is that currently RDT results are subjective, so a test could be positive or negative depending on the health provider's assessment (Miller and Sikes, 2015). More research and development is needed to optimise this innovation.

5.2.3 Intermittent Preventative Treatments (IPT)

Intermittent preventative treatment (IPT) has been introduced to combat malaria in the highest risk groups of individuals – children and pregnant women (WHO, 2015b). Malaria in pregnant women causes higher rates of miscarriage and neonatal death (Schantz-Dunn and Nour, 2009). Intermittent preventative treatment acts by killing existing malaria parasites and preventing future infections (Fokam et al., 2016). One problem, however, is that studies have been able to show that IPT

adoption is correlated to the emergence of chloroquine resistance (Hill and Kazembe, 2006).

The treatment is mainly or always administered as a directly observed treatment (DOT) administered in antenatal care centres (ANC). Treatment coverage remains low in many African countries (Figure 13), despite high ANC attendance (Andrews et al., 2015). This is partly because IPT requires that multiple are doses given at precise times throughout pregnancy, and in areas where ANCs are less accessible this has a significant negative effect on uptake (Hill and Kazembe, 2006, Who, 2013a). A single dose would lead to easier administration and is in the process of being developed for children (Pitt et al., 2012).

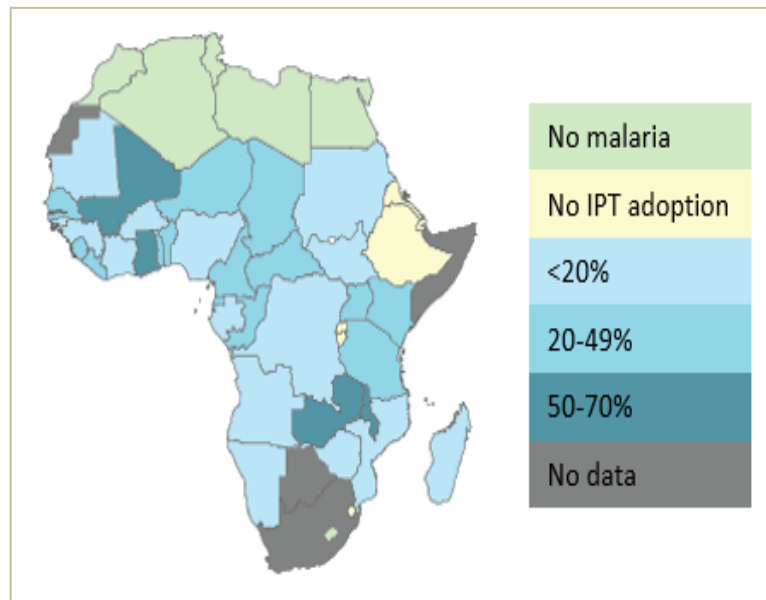


Figure 13: Proportion of women receiving 2 doses of IPT in Africa in 2015.

Based on: Unicef (2016).

Barriers and enablers to the adoption of IPT adoption

Organisational barriers to adoption and diffusion are highlighted in the research literature on IPT. Poor levels of attendance to ANCs, due to factors such as long waiting times, inconsistent clinic opening times, coupled with poor communication and staff attitude are documented (Hill and Kazembe, 2006). Even when ANC attendance is high, other organisational barriers such as poor implementation of

DOT have been observed (Ameh et al., 2016). This is mainly caused by the low health worker to patient ratio. In some regions of Malawi, for example, the ratio is as high as 1:75 (Hill and Kazembe, 2006). Another reason why IPT administration remains low is lack of training and provision of clear guidelines. In a study of Kenya, Tanzania, Namibia, Uganda and Rwanda only a third of ANC patients were consulted by trained providers, and in Kenya even when training was provided, only 24% of staff were familiar with guidelines (Maheu-Giroux and Castro, 2014, Hill and Kazembe, 2006, Lau, 2016).

Government commitment to policy and administrative changes to address these challenges has been observed to help in circumstances where IPT replaced the first line malaria treatment protocol (Hill and Kazembe, 2006). One study showed how significant improvements in IPT administration in the Asembo region, Kenya, could be achieved through better training and guidelines. Originally only 18% of pregnant women received the first dose of IPT and less than 7% received two or more doses; after training courses had been run, 61% received the first dosage and 37% received two or more doses (Ouma et al., 2007).

Supply chain barriers have been a recurring theme in all malaria interventions studied in this review, and again play a role in low adoption rate of IPTs, along with inefficient supply chains and IPT stock outs (Ameh et al., 2016, Andrews et al., 2015, Maheu-Giroux and Castro, 2014, Diala et al., 2013, Ndyomugyenyei and Katamanywa, 2010, Anders et al., 2008, Hill and Kazembe, 2006).

Cultural and social barriers towards IPT uptake focus on common misconceptions about drug administration. In Nigeria, the lack of women's autonomy to receive IPT without consulting a male household member has acted as a barrier to DOT (Ameh et al., 2016). There is also underlying resistance from women, due to lack of IPT awareness and fear of HIV testing in ANCs (Cohen et al., 2015, Hill and Kazembe, 2006). Misconceptions over IPT safety also act as a barrier. There is reluctance to take IPT without eating a meal or whilst being pregnant, a fear of the side effects, while others turn down IPT because they are not actually ill (Hill and Kazembe, 2006). A cultural belief that traditional medicine should be the primary treatment for malaria also affects IPT uptake (Diala et al., 2013).

Research has identified that if the local evidence clearly demonstrates IPT is an efficient treatment, increased community coverage and use can be achieved, especially when this evidence is coupled with efforts to enhance community receptiveness and willingness to try the treatment (Hill and Kazembe, 2006). Improved education can also help, for example by enabling husbands to become more aware of recommended treatments for their pregnant wives and encourage them to abide by proposed guidelines (Diala et al., 2013).

Predictably, economic barriers have also been identified in the research on IPT. When IPT is free, other ANC prescribed medicines are too costly and this impacts ANC attendance (Maheu-Giroux and Castro, 2014, Diala et al., 2013). Another economic barrier to effective IPT uptake is that NGO, mission and private clinics may charge for IPT administration, which is unaffordable (Hill and Kazembe, 2006).

5.3 Genetic modification

5.3.1 Inheritance and genetics – the origins of genetic modification

Genetic modification (GM) of organisms has been a consistently controversial topic since its conception, even though its roots lay in common practices performed throughout the course of human history and pre-history. Humans have been inadvertently altering the gene pool of animals since they first domesticated them in the Neolithic era (Buffum, 1909, Lush, 1937, Wilczynski, 1959). In fact, GM is far from being a recently acquired practice, but has naturally arisen from studies of inheritance and genetics. Humans have been building towards it for millennia, and a mixture of intentional and unintentional human activity has led to the organisms known today.

It was during the British Agricultural Revolution of the 18th century when selective breeding truly became a fine science, pioneered by Robert Bakewell, who was the first to breed cattle for meat, isolating those with desirable characteristics and mating them together with precision and thoroughness previously unknown (Wood and Orel, 1973). His work was an inspiration for Darwin's natural selection theory (Wood and Orel, 1973).

Chapter 5

The most important figures with regards to clarifying the concept of inheritance were Charles Darwin and Gregor Mendel. In 1859, Darwin wrote the controversial 'On the origin of species', which claimed that all organisms once had common ancestors (Darwin, 1979). Darwin, like the 16th and 17th century scholar and scientist Francis Bacon, the 'father of Empiricism', saw great potential and beauty in the 'process of selection' (Bacon and Encyclopaedia Britannica, 1952)

"And we make (by Art) in the same Orchards, and Gardens, Trees and Flowers, to come earlier, or later, then their Seasons; And to come up and beare more speedily then by their Naturall Course they doe." Darwin (1979)

"Slow though the process of selection may be, if feeble man can do much by his powers of artificial selection, I can see no limit to the amount of change, to the beauty and infinite complexity of the co-adaptations between all organic beings, one with another and with their physical conditions of life, which may be effected in the long course of time by nature' power of selection." Bacon and Encyclopaedia Britannica (1952)

Gregor Mendel's laws of inheritance, published in 1865 in 'Experiments in plant hybridization', were the law of segregation of genes and the law of independent assortment, referred to as the foundation of modern genetics (Mendel, 1909). Mendel's work was ground-breaking since it represented the first real convergence of the studies of inheritance and genetics (Mendel, 1909). 'On the origin of species' had a strong influence on Ernst Haeckel, who proposed that the cell nucleus contains the heritable characteristics of an organism in 1866 (Haeckel, 1866). In 1869, Friedrich Miescher discovered nuclein (nucleic acids), which led to the identification of DNA as the bearer of inheritance (Dahm, 2008).

Mendel's theories, when 'rediscovered' and popularized by Hugo de Vries, Walter Sutton and Theodor Boveri in the early 20th century, provoked discussion and accelerated the rate of discoveries in the field of genetics (Genome New Network). What Mendel called 'factors' are known as genes in modern day genetics, and what he called 'forms' are now known as alleles (Mendel, 1909).

The Boveri-Sutton chromosome theory built on Mendel's work and explains the aforementioned identification of DNA as the carrier of genetic information, or more specifically, chromosomes (Genome New Network). It is also known as the chromosome theory of inheritance (Sutton, 1903). It should be noted that Sutton

and Boveri worked independently of each other and arrived at the same conclusion at around the same time (Sutton, 1902, Boveri, 1902).

In the late 1910s, Thomas Hunt Morgan proved and expanded upon the theories of Boveri and Sutton with his experiments on the common fruit fly *Drosophila Melanogaster* (Morgan, 1910), discovering that chromosomes do indeed carry genes. Wilhelm Johansen shortened Hugo de Vries's term, 'Pangene', which is derived from Darwin's term 'pangenesis', to 'gene' (Johannsen, 1909), and also coined the terms 'phenotype' and 'genotype' (Johannsen, 2014). Alfred Sturtevant had previously collaborated with Morgan, studying the *Drosophila Melanogaster*, and created the first gene map while working in his lab in 1913 (Sturtevant, 1913). Hershey and Chase proposed that genes are made of DNA in 1952 by demonstrating that only the DNA of a virus is needed to infect a bacterium (Hershey and Chase, 1952).

Watson and Crick synthesized the work of their predecessors and contemporaries, and correctly suggested the double-helix structure of DNA in 1953 (Watson and Crick, 1953). After the surge of scientific progress in the first half of the 20th century, enough knowledge had been accumulated to allow Watson and Crick to make their discovery and the scientific world to advance to GM.

5.3.2 History of genetic modification

Paul Berg, supported by Stanley Cohen and Herbert Boyer, was the first to design a recombinant DNA molecule in 1972, containing genetic material from two different species; this breakthrough paved the way for all subsequent work in the field of GM (Jackson et al., 1972). In 1973, Boyer and Cohen developed the first GM organism, introducing recombinant DNA into a bacteria cell (Cohen et al., 1973). The daughter cells of this bacterium also expressed the foreign DNA, making the inserted piece of DNA heritable (Cohen et al., 1973).

A year later, Rudolf Jaenisch created the first transgenic animal, when he introduced foreign DNA into the embryo of a mouse (Jaenisch and Mintz, 1974). The mouse did not pass the transgene on to its offspring, thus the possible application of the

technology was questioned. Its potential and great significance was apparent, however (Jaenisch and Mintz, 1974).

Spurred by their success, Boyer and Robert Swanson founded Genentech as first genetic engineering company in 1976 (Russo, 2003). The year after its foundation, the company produced the first human protein, somatostatin, in a bacterium, and by 1982 they received approval from the FDA to market the first recombinant DNA drug, human insulin (Johnson, 1983).

In the 1980s, Philip Leder and Timothy Stewart of Harvard University designed a laboratory mouse to carry an activated oncogene, which increases an organism's chance of developing cancer (Hanahan et al., 2007). Mice were being genetically modified in other ways in the early part of the decade. For instance, rabbit beta-globin was integrated into mice genes in an attempt to achieve germ-line transmission of the transgene to the progeny of the mice (Costantini and Lacy, 1982), which had never been observed in any GM animal at that point. Fruit flies were also extensively experimented on, as researchers followed the example of Thomas Hunt Morgan. Fruit flies are considered ideal for GM research, due to their high reproductive rate, short life span, and few requirements, meaning that several generations of flies can be studied in a short space of time (Rubin and Spradling, 1982).

In 1982, an antibiotic-resistant tobacco plant was the first GM crop to be produced (Fraley et al., 1983). It was created solely for research purposes in order to test the *in vitro* transformation techniques, and was not designed for commercialisation (Fraley et al., 1983). The first genetically engineered vaccine was for Hepatitis B, and was approved in the USA in 1986, replacing the former blood-plasma derived vaccine (Emini et al., 1986). Contrary to the new method, the original approach relied on producing the vaccine in yeast or mammalian cells (Emini et al., 1986).

A strain of bacteria, *Ice-minus P. Syringae* or 'Frostban', designed to protect plants from frost- damage, was the first GMO to be released into the environment, in 1987 (Department of Agricultural Economics, 1988). Immediately after the testing began, there was an attempt to destroy the plants with the bacteria present by anti-GM activists, which was unsuccessful (BBC News, 2002).

Alongside the research on plants and animals, the first human gene map was created in 1987 (Donis-Keller et al., 1987). It has since been revisited and modified. The Human Genome Project was officially launched in 1990 and was completed in 2003 (International Human Genome Sequencing, 2004). The goal of the project was to analyse the sequence of nucleotide base pairs that form human DNA. Its results were independently assessed to ascertain the accuracy, and they were found to have surpassed expectations (Schmutz et al., 2004). Genetic mapping allows great insight into diseases caused by genetic disorders. Thus early diagnosis, new tools for identification and forms of treatment of these diseases became significantly more feasible (Mardis, 2008). Furthermore, genetic mapping can be utilised in many other areas, such as forensic science (International Human Genome Sequencing, 2004).

The first instance of human gene therapy, which implies introducing functional genes into patients with missing or malfunctional ones, occurred in 1989, when tumour-infiltrating lymphocytes were introduced into five patients with cancer (Rosenberg, 1990). The researchers conducting the therapy concluded that "the method of retroviral-mediated gene insertion can be a safe and feasible form of gene therapy in humans" (Rosenberg, 1990). The following year, therapy was performed on a child with an adenosine deaminase deficiency, which was causing severe combined immunodeficiency (ADA-SCID) (Blaese et al., 1995). A retroviral-mediated transfer of the adenosine deaminase gene into the T-cells was conducted, and the patient's immune system normalized, although it only temporarily stimulated production of the missing enzyme and did not create new cells with functional genes, meaning further therapy was routinely needed (Blaese et al., 1995). In 1990, the first transgenic bovine, Herman the bull, was born (Expatica, 2004). He had been microinjected with the human gene coding for the production of lactoferrin, a protein used by the immune system, which his female offspring would express in their milk (Expatica, 2004).

Flavr Savr was the first commercially developed GM food, produced in 1992 and available to the public in 1994 (Redenbaugh, 1992). The tomato was 'designed' to have a longer shelf life and to be resistant to rotting (Redenbaugh, 1992). The

product was very well received by the public upon its release despite the stigma surrounding GM.

Production of Bt Cotton was started in 1993, and by 1995 the technology was approved for commercial use (Burkitbayeva et al., 2016). It has since been adopted by many countries and is the primary crop type for the biggest global cotton producers such as China and India (James and Krattiger, 1996)

Genetic use restriction technology was developed in the 1990s (Pendleton, 2004). This causes second generation seeds of plants to be sterile, in order to uphold the intellectual property rights of developers (Hills et al., 2007). It is yet to be distributed commercially because of numerous debates concerning its potential impact on farmers (Pendleton, 2004, Hills et al., 2007). If the technology becomes widely adopted, GM plants will replace those that have been cultivated over generations, decreasing the overall diversity of farmer's fields and undermining traditional methods, which is a major point of contention (Pendleton, 2004, Hills et al., 2007). Additionally, farmers would have to buy new seeds every year, which is seen by many as a way of large biotech companies exploiting them (Swanson and Goschl, 2000, Visser et al., 2001)

Golden Rice is genetically modified to ultimately contain Beta-Carotene, a source of Vitamin A, in the edible portion of the crop (Ye et al., 2000) (see below). It was designed to mitigate the global health concern of Vitamin A deficiency (VAD) and to address the correlation between populations that consume rice as the main part of their diet, and VAD. The product received bad publicity when large non-government organisations publicly criticised the technology. Greenpeace claimed that "18 kilograms of golden rice would have to be eaten in order to obtain any benefit", and that "billions of pounds that has been spent developing this rice is diverting resources from more sensible ways of tackling VAD" (Dubock, 2014). The Cartagena protocol, an international agreement that seeks to protect biodiversity from potentially harmful GMOs, has also been an obstacle to the commercialisation of this technology (Dubock, 2014).

In 2007 a British biotechnology company Oxitec (Phuc et al., 2007) developed genetically engineered male *Aedes Aegypti* called 'OX513A'. This species of mosquito

can transmit a variety of deadly viruses like dengue and chikungunya to human beings. These modified mosquitoes are sterile and hence their offspring cannot mature to adulthood. When released in the wild, their mating with wild type mosquitoes causes a decline in the overall population of that specific species and hence reduces locally the burden of disease (Phuc et al., 2007). Field trials have successfully taken place in Malaysia and Brazil putting great hope on such technologies for vector control (UK, 2010).

Another innovation, the production of ATryn by GM goats, was given FDA approval in 2009 (Kling, 2009). This anticoagulant is harvested from the milk of these goats for patients with hereditary antithrombin deficiency (Kling, 2009).

The arrival of the first synthetic genome occurred in 2010, and from that genome the first synthetic life form (Gibson et al., 2010).

The emergence of new synthetic gene-editing technologies, like the 'CRISPR/Cas9' system, has broadened the scientific horizon by making genetic engineering faster and simpler to perform. This has left many speculating about its possible applications since its discovery in 1987 (Ishino et al., 1987), but the breakthrough came only in 2011 when scientists demonstrated that gene-editing technologies are transferrable also to other organisms (Hsu et al., 2014). This allowed to make huge gene-editing progress in various domains in a very short period of time. For example, in 2015, Chinese scientists used the CRISPR/Cas9 technology on defective human embryos in order to restore their functionality (Liang et al., 2015). Unfortunately this did not take place in compliance with all the required ethical guidelines and hence the study was interrupted, but it proved the immense possibilities of such gene editing technologies.

Also in 2015, the sale of AquAdvantage salmon, which have an additional growth-hormone regulating gene that allows them to grow year-round, instead of only in the spring and the summer like normal salmon (FDA, 2010), received FDA approval for sale in the USA, making them the first GM animals to be commercially available for human consumption (Waltz, 2016). The release of the product had been delayed for many years. The main reason for these delays were fears that if GM salmon was

released into the wild from the hatcheries, it could outcompete the existing salmon, despite being sterile, with ecological implications.

Today GM remains a field of intense research and development, which is highly regulated due to safety and environmental concerns. It has the potential to be applied in multiple industry streams and has already had a large impact on the pharmaceutical, agriculture, and food industries. GM possesses great potential for medicine and a wide range of innovations have resulted from R&D over the last 40 years. However, controversy over GMOs continues to divide public opinion. There are stringent regulations surrounding use and GM innovations nevertheless these innovations are not always accepted (Bawa and Anilakumar, 2013).

5.4 Systematic review: Key factors for the adoption and diffusion of GM innovations

Section 5.3.2 elucidates the most important historical GM intervention discoveries, selected from an initial review of the historical development of the technology. Bt cotton, a genetically modified plant that produces insecticidal toxins, Golden Rice, a modified variety of rice that could potentially eradicate vitamin A deficiencies in certain Asian areas, GM vaccines, vaccines that are modified for a more specific reaction, and Oxitec's sterile male mosquitoes for the fight against dengue, were selected as the most relevant GM innovations within the last decade. Hence, the systematic literature review of GM innovations focussed on the barriers and enablers which have led to an effective adoption of these interventions, in order to yield lessons learned for the adoption and diffusion of GM mosquitoes.

5.4.1 Bt Cotton

Helicoverpa armigera (cotton bollworm) is a major pest in the agriculture industry (Beyo et al., 2004). It affects an array of harvestable crops, but causes most damage in terms of cotton yields (Liao et al., 2002). Over the years, farmers have combatted the effects by applying mass volumes of insecticide and pesticide spray, but this causes significant detrimental health and environmental effects (Pray et al., 2001).

Therefore, research focused on identifying a mechanism to sustainably control cotton bollworm. In 1996, Monsanto, an agrochemical company developed Bt cotton (Pray et al., 2002). Bt cotton is a genetically modified strain of cotton that has genes incorporated from *Bacillus thuringiensis*. The inserted genes are responsible for the production of Bt toxins that eliminate bollworms (Utia, 2009). Growing insecticide and pesticide resistance has led to Bt cotton adoption in some countries (Pray et al., 2002) – it is currently grown in 15 countries worldwide and of the top ten cotton producers worldwide only four have not adopted the innovation (Burkitbayeva et al., 2016). There is debate on Bt cotton's efficacy and whether the costs and benefits of adoption give rise to a significant net gain. The literature repeatedly states that Bt cotton usage leads to less insecticide spraying, higher cotton yields and is more profitable, although seed cost is significantly higher (Qaim et al., 2006, Gouse et al., 2005, Qaim and De Janvry, 2003). This review will highlight the key enablers and barriers of Bt cotton adoption and reasons why some countries have rapidly adopted the innovation and others have not (Lau, 2016).

Barriers and enablers to the adoption of Bt cotton

Bt cotton coverage varies dramatically dependent on region. In 2014, GM cotton, including Bt cotton, accounted for 68% of cotton agriculture. There are natural barriers to why GM coverage is not even greater (Burkitbayeva et al., 2016). For example in Central Asia there is low demand for Bt cotton due to the favourable climate for cotton and low levels of pest infestation, which makes Bt cotton more costly to adopt than cultivating conventional cotton (Chaudhry, 2008).

Organisational barriers include that fact that large agricultural companies monopolise the seed distribution market, preventing private companies and governments from competing. This erodes government enthusiasm in the innovation, so there is little effort to adopt and diffuse the technology (Pray et al., 2002). The high levels of regulation regarding GM also act as a significant barrier. Countries situated in Central Asia have not approved GM cotton and countries in the European Union cannot take up the technology due to strict regulations. Factors such as consumer aversion, whereby consumers are heavily influenced by negative

media remarks on GM, also have an effect on adoption. Organic farming is also a barrier, since for a product to be certified organic regulators prohibit the use of GM strains (Burkitbayeva et al., 2016).

There are many economic benefits in adopting Bt cotton, but the literature search also highlighted economic barriers. Across the Bt cotton market, the genetically modified seeds cost considerably more. In India, GM seeds were 321% more expensive than conventional seeds (Qaim et al., 2006). This was one of the reasons Bt cotton adoption in Argentina was so slow – three years after introduction in the country, Bt cotton only covered 5% of national cotton acreage. In comparison, GM soybeans had almost 100% coverage in the same timeframe (Qaim and De Janvry, 2003). Another related economic barrier is the low market price of cotton, affecting the profitability of cotton production overall. Additionally, the absolute cost base for machinery and labour is significantly higher due to the increased output during harvest. The study carried out by Qaim et al. showed that 40% of Bt cotton adopters experienced lower gross margins (Qaim et al., 2006).

Technological constraints regarding Bt cotton also have an impact on adoption. In China, although there is widespread adoption, farmers still administer large quantities of pesticide and insecticide. This is a result of low quality seed distribution, expressing ineffective levels of Bt toxin and increasing bollworm resistance (Huang et al., 2014, Pray et al., 2001). This has been observed in other locations, such as India and South Africa (Gruere and Sun, 2012, Hofs et al., 2006).

Key enablers of Bt cotton were discovered throughout the literature review. Economic benefits arising from increased cotton yields (Kathage and Qaim, 2012, Frisvold et al., 2006, Toenniessen et al., 2003) are a key precondition for widespread adoption (Qaim and De Janvry, 2003). In 2007, global the economic benefit from Bt cotton was estimated to be USD 1.4 billion (Frisvold and Reeves). In India cotton yields have increased from 1.5 quintals to 5 quintals after adoption (Gruere and Sun, 2012). In addition to increased cotton yields providing greater profits, insecticide and pesticide costs are reduced as Bt toxins operate more efficiently. In California, insecticide cost savings are as large as USD 41.49 dollars per acre (Frisvold et al., 2006). Lower amounts of insecticide and pesticide applications indirectly reduce

cost further, through labour savings and diesel savings that correlate with fewer tractor hours (Gouse et al., 2005, Lau, 2016).

Environmental factors have a role in increased adoption rates. Ecological benefits were experienced in many circumstances post-adoption, primarily as a result of reduced insecticide and pesticide usage. A study in China showed that there was a significant reduction in pollution levels after Bt cotton adoption. In conjunction with this, an increase in biodiversity was observed (Pray et al., 2001). Additionally, in South Africa, increased populations of pollinators such as ladybirds and lacewings were recorded after adoption (Gouse et al., 2005). Another environmental advantage is that the increase in yield allows for the preservation of tropical forest and other natural landscapes that would otherwise be converted for agriculture (Toenniessen et al., 2003).

The adoption of Bt cotton has also been found to generate social benefits. Cotton bollworms were a major pest prior to Bt cotton development. Bt cotton allows farmers peace of mind, so they can concentrate on cultivating other crops (Gouse et al., 2005). Other social advantages include the generation of more labour opportunities for women during the harvest season as cotton yields increase, and poverty reduction (Subramanian and Qaim, 2010, Subramanian and Qaim, 2009). Poverty and living standards have changed in countries that have adopted Bt cotton. Consumption expenditure is a measure of living standards and in India the consumption expenditure of farmers adopting Bt cotton increased by 18% during 2006-2008 (Kathage and Qaim, 2012).

According to the literature search, health improvements also act as an enabler. Positive health benefits for farmers were observed in both China and India. As pesticide and insecticide use is reduced, exposure to these harmful chemicals also decreases. Therefore incidences of pesticide poisoning became less common (Gruere and Sun, 2012, Pray et al., 2001, Lau, 2016).

5.4.2 Golden Rice

Vitamin A deficiency (VAD) is a growing public health concern. In 1995, it was estimated that pre-school populations in over 45 countries suffered from symptoms of VAD (WHO, 2009). VAD onset is mainly caused by a diet lacking heavily in vitamin A, if this occurs over a prolonged period of time it can lead to harmful consequences such as blindness and increased immune system weakness (WHO, 2009). Together these factors negatively impact mortality rates, especially in children. Therefore, an innovation that decreased VAD was necessary to help achieve Millennium Development Goal 4, reducing child mortality (UN, 2015). Rice is a staple food in over 50% of world populations and there is a correlation between populations that consume rice as a staple food and the lack of vitamin A intake (Moghissi et al., 2015, Dubock, 2014). Therefore, rice provided an effective target to be genetically modified and to increase vitamin A consumption.

In 2000, successful results were published from an 8 year study that aimed to incorporate two genes, *psy* and *crt 1* into the rice genome. These genes were associated with an endosperm-specific promoter, which leads to synthesis of β -carotene, a chemical precursor to vitamin A in the edible portion of rice. (Ye et al., 2000). At the time of conception, this was regarded as a significant breakthrough to decreasing the prevalence of malnutrition. Adoption of this intervention was expected but barriers were met and at present day the technology has yet to be commercialised (Mayer et al., 2006, Lau, 2016).

Barriers and enablers to the adoption of golden rice

There have been a number of significant barriers to adoption of golden rice. Technologically, the original golden rice strain failed to provide enough β -carotene unless a large portion was consumed. This meant that NGOs including Greenpeace were able to portray a damaging image to the public, with claims that “18 kilograms of golden rice would have to be eaten to obtain any benefit” as well as stating that “billions of pounds could have been invested in more sensible ways of tackling VAD” (Dubock, 2014). This technological and public image challenge was overcome in

2005, with the creation of a new strain that delivers 50-60% of the recommended daily allowance of vitamin A in a 72 gram portion (Moghissi et al., 2015).

There are also policy and safety barriers. The Cartagena Protocol, followed by 170 parties, is an agreement that protects against the risks of GMOs (Dubock, 2014). This has had an impact on the adoption of golden rice, despite many field studies that show it is safe (Dubock, 2014, Grune et al., 2010, Lu and Snow, 2005). Approval from regulating bodies, as well as greater public receptiveness, are therefore seen as the main factors that would help enable golden rice adoption.

5.4.3 GM Vaccines

Vaccination has been occurring since the late 1760s when Edward Jenner pioneered inoculation with cowpox as a mechanism of protection against smallpox (Gross and Sepkowitz, 1998). Since then vaccines have dramatically improved health statistics worldwide by reducing the prevalence of disease (Aryamvally et al., 2016). The process used to develop conventional vaccines leave risk for reversion from the attenuated strain to a more potent strain, causing vaccine-induced disease. Vaccines that are genetically engineered can avoid this because GM vaccines are modified to have very specific properties that are well defined, so reversion is not possible (Dertzbaugh, 1998). Despite this research, the development of GM vaccines has proved to be a long and fruitless process in most cases. Only in 2013 did the FDA approve the first GM vaccine, FluBlok (FDA, 2015, Schagen et al., 2014). Subsequent introduction of other GM vaccines has been also slow, lots of research has revolved around the concept of edible vaccines. This holds great potential for the future and a group in India has already successfully grown a banana that is modified to also be a hepatitis B vaccine (Kumar et al., 2005). The enablers and barriers to GM vaccine adoption must be characterised as it will aid efficient introduction of GM mosquitoes (Lau, 2016).

Barriers and enablers to the adoption of GM vaccines

Currently, as there are so few GM vaccines in circulation it is hard to systematically identify both barriers and enablers to this innovation. The most significant barrier identified is the stigma behind GM, partly reflected in the stringency of regulations and directives, and partly in public opinion (Bawa and Anilakumar, 2013). There remains uncertainty over GM safety, especially whether designed characteristics can be transferred to wild type strains. Another popular belief against GM is that scientists are “tampering with mother nature”, creating organisms that are not as nature intended (Bawa and Anilakumar, 2013). Many take the viewpoint that conventional vaccines are already approved and have proven to be safe and efficient, thus the added value of the development of a GM vaccine to replace this is not seen. This point is extremely valid and is another possible reason why there is reluctance over adoption of GM vaccines (Aryamvally et al., 2016, Dertzbaugh, 1998).

The main enabler noted in the literature is achieving FDA approval or approval from a similar regulating body (Bawa and Anilakumar, 2013). This allows the innovation to be introduced to the public. At this time, it is very difficult to obtain approval. As well as this, another enabler is the potential advantages that can be harnessed through GM vaccine adoption, especially edible GM vaccines. Currently, cost and infrastructure are barriers to distribution of conventional vaccines, so edible GM vaccines can potentially overcome these barriers (Aryamvally et al., 2016, Lau, 2016). A low production cost, the ease of storage and administration could also improve accessibility in less developed countries (Aryamvally et al., 2016).

5.4.4 Oxitec’s self-limiting GM Mosquitoes

Currently, half of the world’s population is at risk of dengue fever (WHO, 2016a). Dengue is transmitted by female *Aedes aegypti* and *Aedes albopictus*, both are mosquitoes that also spread other diseases such as yellow fever and zika virus (WHO, 2012a). Dengue fever causes flu-like symptoms which aren’t life threatening, but if the virus persists, severe dengue ensues. The symptoms of severe dengue can include organ impairment and respiratory distress, medical attention is required

otherwise there is a high risk of death (Guzman et al., 2010). Since 1955, the frequency of dengue fever incidences has increased radically and is a cause for greater global concern. The estimated annual incidence rate is 390 million, of which 25% of these cases lead to severe dengue (WHO, 2016a, Bhatt et al., 2013). In 1970, dengue virus was endemic to only nine countries; now over 100 countries worldwide are endemic to dengue (WHO, 2016a).

As the rate of incidence increases, attention has turned to innovations that might help combat the incidence of dengue fever. In 2007, Oxitec developed a genetically modified species of *Aedes aegypti* that could potentially solve the problem (Phuc et al., 2007). The genetically modified mosquito, called '*Aedes aegypti* OX513A' has had a dominant lethal gene inserted into its genome by Phuc et al. (2007); this gene is responsible for sterility. When male GM OX513A mosquitoes mate with female wild types, subsequent offspring will not mature to adulthood. This causes a large decline in mosquito populations, consequentially leading to lower incidences of dengue fever (Lau, 2016).

While this approach works theoretically, studies had to be carried out to assess how efficient this GM mosquito would be in the wild. Field trials have occurred in Grand Cayman, Malaysia and Brazil (GeneWatch, 2012). In Grand Cayman, an 80% population reduction was observed over 23 weeks and the study carried out in Brazil resulted in a 96% population reduction within a 6 month period (Dhang, 2014, Harris et al., 2012). The successful results and approval of OX513A's safety has led to adoption of the innovation in Grand Cayman. Prior to the planned deployment of GM mosquitoes, Oxitec highlighted the importance of community receptiveness and planned community programmes to increase understanding behind the technology (Warren, 2016). In 2010, Oxitec also developed a GM strain of *Aedes albopictus* (Labbé et al., 2010). Testing has just started and it will be interesting to see the results compare to the OX513A.

Barriers and enablers to the adoption of Oxitec mosquitoes

Technologically, concerns are apparent over how efficient Oxitec's innovation is. While field studies have highlighted how effective this intervention can be, other studies have suggested that a temporary decrease in mosquito populations due to an ineffective intervention could exacerbate dengue spread (GeneWatch, 2012). Organisations such as GeneWatch have also challenged Oxitec's introduction protocol, claiming short cuts are being taken and full risk assessments aren't being fulfilled (GeneWatch, 2012). This technology is therefore at the stage of evidence development, prior to gaining approval from regulating bodies. Deepening community support to help to introduce this technology successfully may only occur after these both these steps (Lau, 2016).

5.5 Discussion

There is a significant research literature on adoption and diffusion of health innovations, outlined in Chapter 2. This identified that health technologies can be complex, involving both 'hard' and 'soft' components, that innovation in health technologies can range from incremental to radical changes, and that the impact of their introduction can be unpredictable and have ramifications outside the immediate context of their introduction. This is due to the complexity health systems and nature of interactions between their elements (Atun, 2012). It was also shown that commercialisation, adoption and diffusion are a crucial part of the overall innovation process for new technologies, but often in a non-linear way, with feedback and evolution between the different stages.

This chapter has focused on lessons from research on the introduction of technologies pertinent to the chosen domain of this PhD study – the control and eradication of malaria, and the development and introduction of GM technology. The systematic reviews reported here have highlighted the enablers and barriers during the adoption and diffusion of key malaria interventions that have been identified, along with those for key GM innovations.

Recurring factors were identified in both streams of technology and demonstrated the importance to overcome organisational, supply chain and cultural/social barriers. Organisational barriers were also noted throughout the literature search. In regards to malaria interventions, lack of training and user guidelines were cited as a significant barrier (Zongo et al., 2016, Maheu-Giroux and Castro, 2014). In many cases this has led to incorrect implementation and poor understanding of the technology (Ameh et al., 2016). Regulating bodies provide strict and stringent guidelines towards GM technology (Burkitbayeva et al., 2016), which so far has acted as a barrier to certain innovations based on GM technology, as observed in Bt cotton, GM vaccines and Golden Rice (Dubock, 2014).

Supply chain barriers were constantly mentioned throughout the literature review, especially in terms of malaria innovations. Many low-income countries experience stock outs that affect intervention adoption, arising from poor infrastructure (Zongo et al., 2016, Andrews et al., 2015).

Cultural and social barriers are the most significant issue to overcome. Different countries exhibit different cultures and social behaviours that can disable innovation adoption. The literature search highlighted that this had occurred during all three malaria interventions and are even more problematic in regards to GM interventions. The lack of community understanding can be pinpointed as a reason for this, emphasizing the need for education. This was shown in Ghana, where an intervention programme that was also culturally relevant lead to a 98% preference for the technology (Miller and Sikes, 2015, Lau, 2016). The social stigmatism behind GM technology has also affected adoption and diffusion of GM mosquitoes. In the case of 'Oxitec Mosquitoes' (Warren, 2016) there has been ethical criticism concerning "the sanctity of life", whereby it is regarded that a species towards extinction is fundamentally wrong (Pugh, 2016).

The chapter also described the current progress of GM technology, including GM modification on mosquitoes. From the discussion on Oxitec, it is clear that the development phase is inextricably bound up with evidence gathering through field trials, along with public education to increase understanding and engagement with

the regulatory process. The 'Schumpeterian trilogy' (see Section 2.1.4) therefore clearly involves a messy, non-linear process in this instance.

In conclusion, the literature review has highlighted that interventions react differently in different health systems and it is a challenge to predict how efficiently a technology will be adopted and diffused. The thesis now turns to the empirical material of our case, in order to explore the extent to which the factors described in the prior research on health innovation adoption and diffusion can help the author to understand the introduction of GM mosquitoes and other malaria interventions in Burkina Faso. The next chapter describes the Target Malaria project and the underlying GM mosquito technology.

6 The case study: genetically modified mosquitoes in the fight against malaria – a complex innovation

6.1 Target Malaria

Target Malaria (formerly ‘Homing Endonuclease Genes’ (HEG) Consortium) is a not-for-profit research consortium with the vision to eradicate malaria and, potentially, other vector-borne diseases (Target Malaria, 2016c). Founded in 2005 as a university-based research programme with the aim of developing a unique innovative technology for vector control, it has grown to a wider consortium of over 100 scientists, community engagement and risk assessment specialists, as well as regulatory experts from Africa, North America and Europe (Target Malaria, 2016c).

Target Malaria began under the Grand Challenges in Global Health initiative, which fosters scientific and technological innovation to solve key health problems in the developing world. Until August 2016 (including the period of this PhD study), the project was funded by a grant from the Foundation for the National Institutes of Health (FNIH) through the Vector-Based Control of Transmission: Discovery Research (VCTR) programme of the Grand Challenges in Global Health Initiative. Currently, Target Malaria is funded through a programme of the Bill & Melinda Gates Foundation (Target Malaria, 2016c).

Under the project ‘Controlling the mosquito vectors of malaria with engineered endonucleases’ scientists within the Consortium are developing a new technology that uses genetic modifications in the specific strains of mosquito that transmit the disease to suppress their ability to reproduce (Burt, 2003, Burt and Koufopanou, 2004). The technology arising from this work will be genetically modified (GM) *Anopheles* mosquitoes, the release of which will lead to a progressive reduction over successive generations in the numbers of native mosquitoes able to carry and transmit malaria until there are too few remaining to sustain transmission of the disease (Burt, 2003, Burt and Koufopanou, 2004). Hence, if successful, the number of malaria transmitting mosquitoes will gradually be reduced within large regions, thereby reducing and hopefully eliminating malaria in that region. Along with other

malaria elimination tools, the GM technology from Target Malaria could also be a key tool for global eradication.

6.1.1 Target Malaria's technology

The genetic modification inserted within the mosquito strains comprises a gene-targeting enzyme (nuclease) that recognises and cleaves a very specific, but also fairly long and hence quite rare, DNA sequence (Burt, 2003). This enzyme can be either based on engineered versions of naturally occurring proteins – called ‘Homing Endonuclease Genes (HEGs)’, found in many common small organisms such as yeasts, other fungi, algae, and moulds (Chevalier and Stoddard, 2001 Sep 15) – or based on synthetic enzymes of the clustered regularly interspaced short palindromic repeats associated with a ‘Cas9’ nuclease (CRISPR/Cas9) system (Hammond et al., 2016). The main peculiarity of all these nucleases is that, if designed to cut and insert themselves within the specific DNA sequence that they recognise, they are capable of copying themselves from one chromosome containing the nuclease to its homologous chromosome not containing the nuclease in a process called homing (Burt, 2003). In fact, when introduced in the *Anopheles* mosquitoes, these nucleases can be used to identify and cut through essential genes (Hammond et al., 2016). These are the genes that are essential for either the survival or the fertility of the mosquito. Hence, the targeted gene is no longer able to function, and the mosquitoes are consequently affected according to the nature and importance of the selected essential gene.

The ultimate goal of Target Malaria's scientists is to create a strain of modified malaria mosquitoes that can pass these modified genes to a disproportionately high percentage of their offspring, so that the modification spreads throughout the specific population relatively quickly and is effectively ‘self-sustaining’. This mechanism of increase in gene frequency throughout a population breaks the normal rules of gene inheritance and is referred to as a ‘gene drive’ mechanism, the unique feature of Target Malaria's technology.

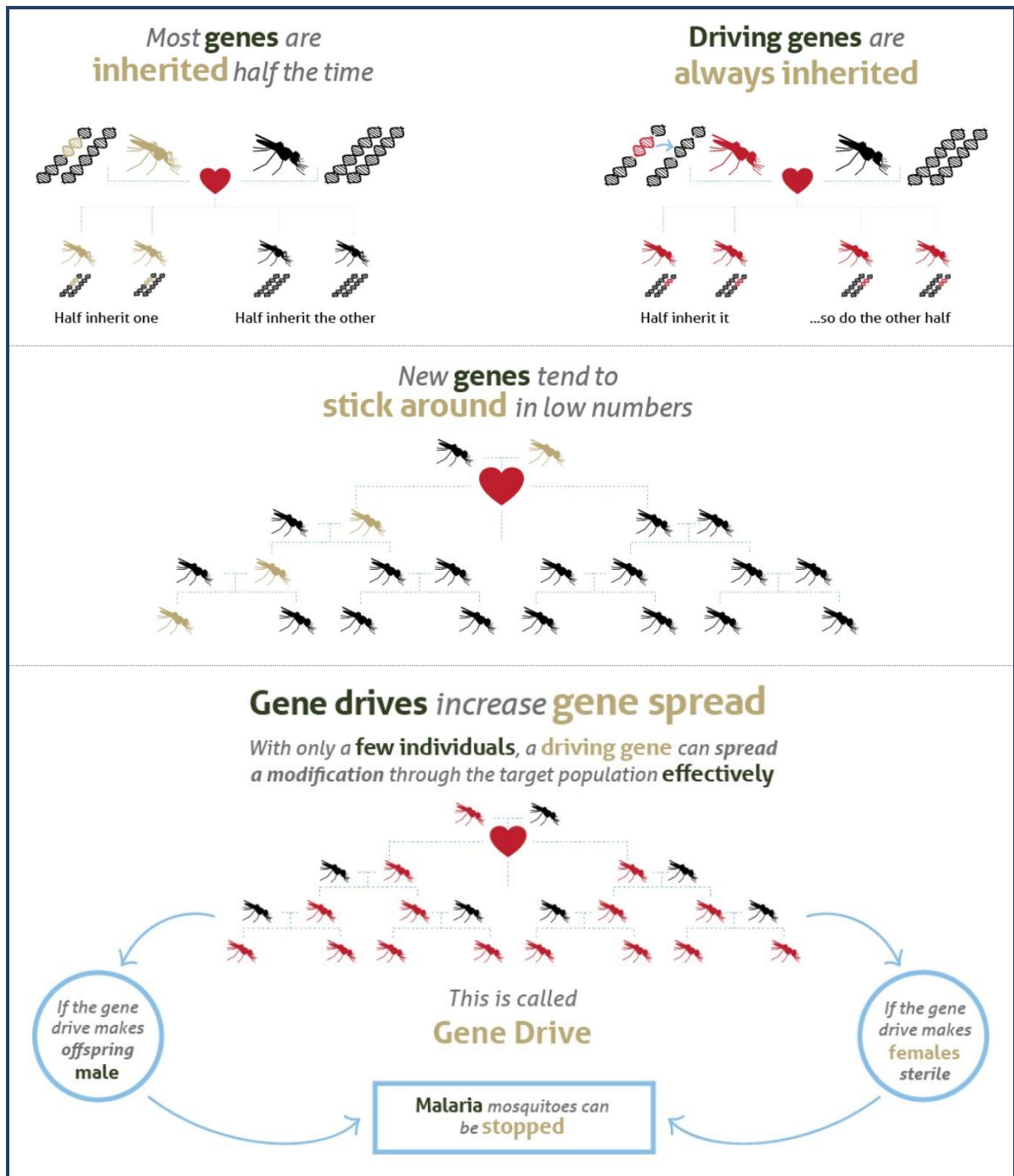


Figure 14: Infographic on gene drive mechanisms for malaria elimination.

Based on: Target Malaria (2016a).

How gene drive works

Target Malaria's aim is to generate modified malaria mosquito strains that entail a gene drive mechanism and are hence effectively 'self-sustaining'. But how exactly does a gene drive mechanism work?

Every living organism has deoxyribonucleic acid (DNA) which is the carrier of genetic information and contains all the information needed by that organism to develop, live, and reproduce. DNA is also the main constituent of chromosomes, a thread-like structure found in the nucleus of most living cells, carrying genetic information in the form of genes. In fact, genes cause the traits that determine our differences. Like humans, mosquitoes are 'diploid', meaning that they carry two copies of each gene on two chromosomes (homologues), one derived from each parent.

The gene-targeting enzymes (either engineered HEGs or synthetic nucleases) used in Target Malaria's technology recognise specific gene sequences on one of the two chromosomes, cut it and insert themselves inside this sequence, making it resistant to further cleavage (Burt, 2003, Windbichler et al., 2011, Hammond et al., 2016). When the endonuclease then comes into contact with its chromosome's homolog that does not contain the endonuclease gene, it cuts the intact target sequence, prompting the cell's own DNA repair machinery. This intracellular repair mechanism of the target organism recognises the mismatch between the two DNA sequences and uses the intact chromosome, which contains the endonuclease gene, as a template to restore the break (homologous recombination). By doing so the functionality of the gene is fully disrupted as both copies are disrupted by the nuclease.

Furthermore, this process can be switched on and off quite precisely through the use of specific promoters that can restrict the expression of the nuclease gene to specific tissues. If expressed in the germline, the homing process will occur in the cells that go on to make the gametes (eggs and sperm), and will be passed efficiently from parent to a high number of offspring, rapidly increasing in frequency within the population (Galizi et al., 2014, Galizi et al., 2016).

Implementing gene drive in the fight against malaria

When it comes to implementing a gene drive system to eradicate malaria there are three principle strategies that can be adopted: population-wide gene knockout, biasing the sex ratio, or insertion of malaria resistance (Nolan and Crisanti, 2017). The first two are population suppression mechanisms, while the third is a population replacement mechanism.

Population-wide gene knockouts target the disruption of endogenous mosquito genes through gene drive systems (Nolan and Crisanti, 2017). This allows the spread of a deleterious modification through the mosquito population to either reduce overall mosquito numbers or to modify the mosquito capacity to support malaria parasite development (Nolan and Crisanti, 2017). The most effective essential genes for this purpose of population suppression are female fertility genes (Burt, 2003). In this case, mosquitoes with only one copy of the defective gene are fertile, but through the gene drive mechanism the modified gene finds its way into all of the mosquito's gametes. By doing so, the modification is transmitted to all of their offspring. As the gene drive element increases in frequency in the population, so does the probability of the offspring receiving a copy of the modified gene from both parents (see

Figure 15). This would result in offspring with no functional copy of the female fertility gene and hence a disrupted fertility. All such females in this class are sterile, while males will continue to transmit the gene drive to all offspring. This would lead to a reduction of the population of malarial mosquitoes and eventually to an area-wide suppression of that species.

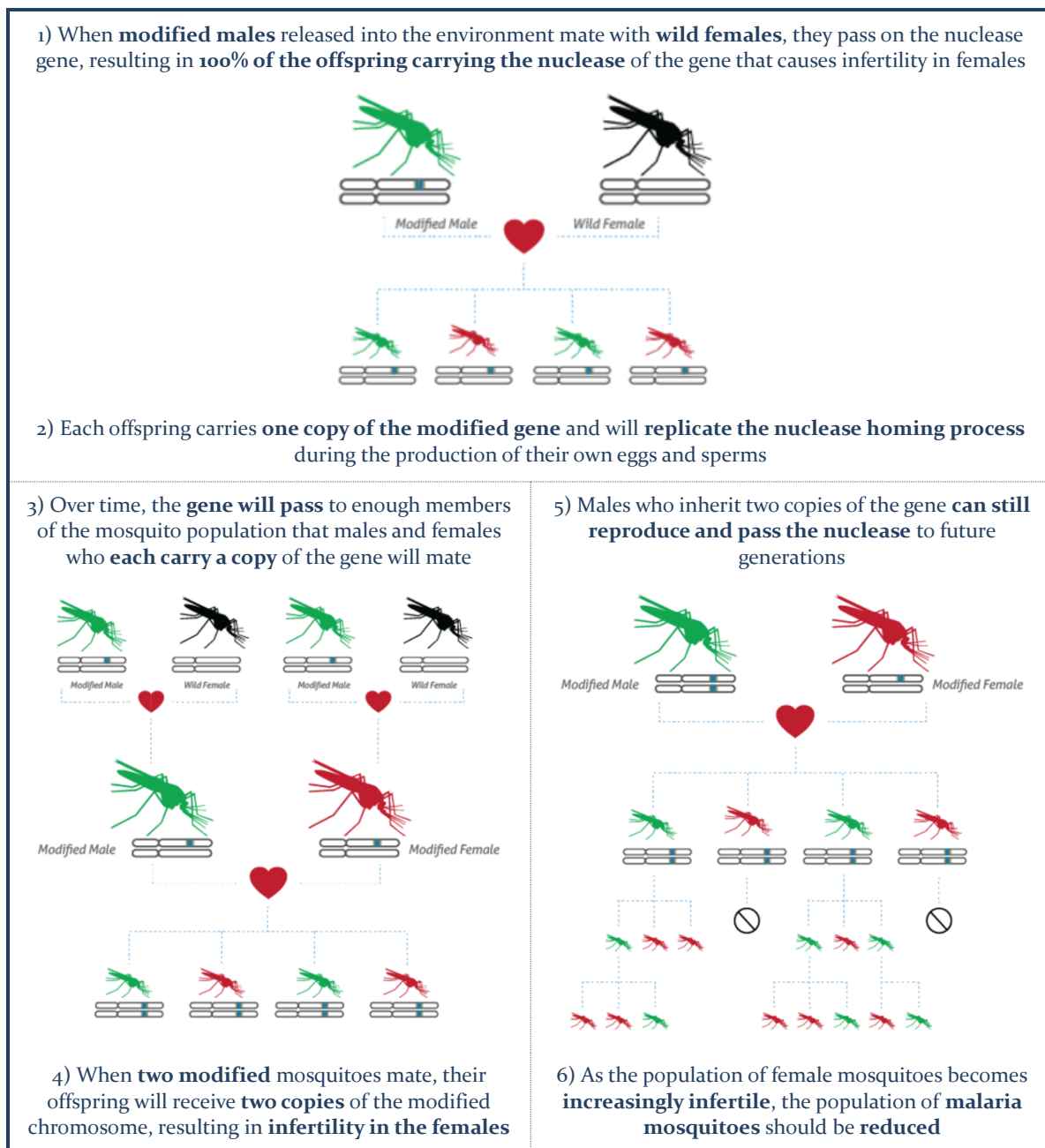


Figure 15: Infographic on gene drive mechanisms for population-wide gene knockouts.

Based on: Target Malaria (2016a).

Mechanisms based on biasing the sex ratio of offspring (also called sex-distorter mechanism) rely on gene drive systems to bias the inheritance of the male sex chromosome (Y chromosome), distorting the sex ratio toward males. This can be achieved through the selective destruction of the X chromosome during sperm maturation in males. In fact, Target Malaria researchers have proven that engineered versions of naturally occurring HEGs can be used to target a specific repetitive sequence, found in several hundred copies only in the X chromosome of *Anopheles gambiae* mosquitoes (Galizi et al., 2014, Galizi et al., 2016). As a result, 95% of all viable sperm contain a Y chromosome and produce male offspring containing the nuclease (Windbichler et al., 2008). Depending on the grade of engineering done on the natural HEG and the location of the inserted nuclease, the male offspring can have different degrees of fertility ranging from sterile males to a self-sustaining gene drive that produces fully viable male offspring all carrying the nuclease (Burt, 2003). The self-sustaining modification would over time also drastically reduce the number of female mosquitoes of the targeted species present in the wild and hence also in the case lead to an area-wide suppression of that species. Furthermore, given the fact that only female mosquitoes bite and hence are able to transmit the Plasmodium parasite any intervention of this type should lower disease transmission.

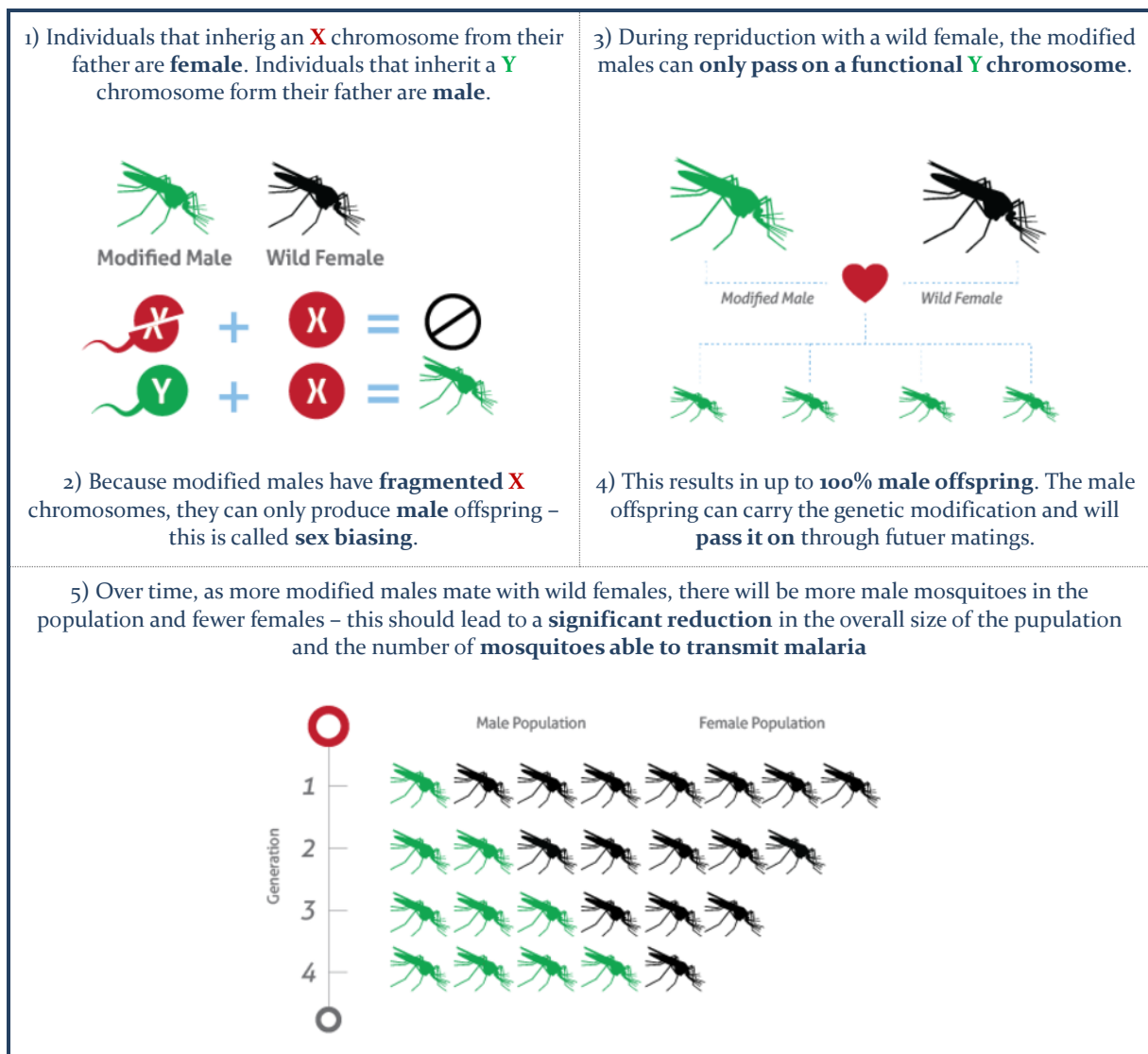


Figure 16: Infographic on gene drive mechanisms for biasing mosquito sex ratio.

Based on: Target Malaria (2016a).

Malaria resistance can be induced by equipping mosquitoes with an anti-parasite cargo such as a transgene that produces an antiparasitic peptide that directly fights the malaria parasite within the mosquito (Gantz et al., 2015). Unlike for suppression mechanisms, when a gene drive system is designed to carry such a cargo, the desired outcome is dependent on the nature of the cargo rather than the genomic location of the insertion of the gene drive element. Currently, some researchers have been able to demonstrate partial proof the principle of this technology (Gantz et al., 2015). However, an effect has not yet been shown on the parasite nor have the population dynamics of such an element been tested.

Given that mosquitoes breed rapidly (in about a month), modelling shows that modified mosquitoes carrying gene drive systems for population suppression strategies would be able to spread through the target mosquito population in just a couple years and hence have the potential to quickly have an impact on the burden of disease (Deredec et al., 2008).

While other research groups focus exclusively on the development of population replacement strategies, scientists within the Target Malaria Consortium are at the forefront in the development of the two elimination strategies and have focussed the technological development pipeline on those.

6.1.2 Characteristics of GM mosquitoes based on a gene drive mechanism

As mentioned in the previous sections, Target Malaria's technology utilises a widely-used approach: malaria control through vector (mosquito) control. The innovation is in the use of very complex technology involving GM mosquitoes based on a gene drive mechanism to suppress their ability to reproduce or survive. In fact, the loss of function of the targeted essential genes will reduce the number of mosquitoes able to transmit malaria.

Scientists have been working on ways to disrupt mosquito reproduction for a long time, but the use of genetic modification to achieve this goal offers many potential advantages for vector control. The resulting final technology will provide area-wide, sustainable, durable, and low-cost protection, and has the potential of being a valuable tool for malaria eradication, notably in areas where disease transmission levels are high and current control methods are not expected to be adequate to achieve malaria eradication (Hay et al., 2009).

Species specificity: the Target Malaria technology targets only specific malaria vectors – *Anopheles gambiae*, *Anopheles coluzzii* and *Anopheles arabiensis*. As described in Section 5.1 over 3,500 species of mosquito exist worldwide, out of which 837 are found in Africa (CDC Centers for Disease Control and Prevention, 2015a). The single cluster of the three very closely related species targeted specifically by the

technology constitute roughly 1% of the total mosquito population. In fact, this type of technology allows very precise targeting of modifications at the level of DNA, and provides a way to be extremely species specific. On the contrary, when applying chemical control and environmental management measures the whole ecosystem is impacted and negatively influenced. In the past, especially the use of DDT has proven to have severe negative effects on human health as well as strong polluting effect on the whole ecosystem in which it is sprayed.

Spread of transgenic trait in local population: Target Malaria's self-sustaining technology carries a genetic modification that can spread and persist over time in a local mosquito population, resulting in a self-sustaining technological intervention. Over time the genetically modified mosquitoes would autonomously spread the modification to the targeted wild-type *Anopheles* population in the area, leading to a reduction of malaria-transmitting female mosquitoes. This is a great advancement in comparison to simpler Sterile Insect Technique (SIT). The SIT is a widespread technology for vector control in agriculture which produces sterile insect males by ionizing radiation or chemosterilisation (Helinski et al., 2009). These are subsequently released in masses in areas where the wild type insects are viewed as plagues and lower the population. These have an immediate effect on population size, but need repeated, large-scale applications to keep the population suppression at acceptable levels (James, 2005, Sinkins and Gould, 2006). The technological advancement of a gene drive system indirectly brings four further benefits:

- **Efficacy:** Some agricultural pests have been successfully controlled by mass releasing males that have been sterilized by irradiation. However, for *Anopheles* mosquitoes, studies have shown that the dosage of radiation needed to sterilize males also substantially impairs their mating competitiveness, leading to an inefficient product. This is not the case for self-sustaining GM mosquitoes, increasing its efficacy compared to similar technologies.
- **Better adaptability to the environment:** The increased fitness of these GM mosquitoes makes them also better adaptable to the harsh environmental conditions present in the countries where the technology would be released.

- **Simplified deployment mechanisms:** Malaria in Africa is predominantly a rural disease, and it would be hugely challenging to generate the billions of sterile males needed to inundate the natural population. This technology requires much smaller numbers of males be released and, since the mosquitoes are self-sustaining, they can spread, thus substantially reducing not just the quantity of mosquitoes released but also the frequency and amount of those releases.
- **Cost effectiveness:** Both the fact that reduced numbers of mosquitoes are needed, as well as the fact that the number and complexity of those releases is limited, leads to increased cost effectiveness.

Hence, Target Malaria's technology represents an advancement not only in terms of technological innovation, but also in respect to economic and logistical problems encountered by SITs due to constant breeding and reintroduction of sterile mosquitoes in the wild as well as to other malaria technologies based on insecticides.

No change in human habits: Unlike bednets, vaccines, preventive therapies, or medications Target Malaria's technology is a mosquito-driven malaria prevention strategy which would have protective benefits without interfering with people's daily lives (e.g. need to travel far to get the medications). Further, given that the mosquitoes themselves do the work of delivering the protective effect, the technology is immune to human failure in complying with the correct utilisation of the technology (e.g. incorrect use of bednets).

Equitable: Given the nature of the technology, it will provide protection for everyone in the community, regardless of their education, wealth or ability to access healthcare services. Further, given the not-for-profit organisational set-up of Target Malaria, affected countries and members of the local communities will not need to bear the cost of developing the technology through the price of the product, as is the case with other malaria control methods.

Complementary: The efforts undertaken so far in the combat against malaria have shown that the disease can only be eradicated by the combined use of different technologies. Target Malaria's technology does not just bring a number of additional practical advantages compared to other malaria prevention tools, but can be perfectly combined and have no negative influence on other tools such as ITNs, IRS, malaria prophylaxis, and possible vaccines. Moreover, it could also leverage the positive effect of other interventions like vaccines, bednets and chemoprophylaxis.

6.1.3 Characterisation of the Target Malaria's technology – GM mosquitoes

Based on the theories and definitions on healthcare technologies and innovation in healthcare described in Sections 2.1.2 and 2.1.3, the question arises how Target Malaria's innovative and complex technology should be defined.

In contrast to SIT based insects, which were mainly introduced to overcome agricultural pests, GM mosquitoes for malarial eradication are not a technology designed for other sectors which indirectly have an effect on the improvement of health. According to Howitt et al, healthcare technologies are directly applied to overcome health needs and are precisely intended to prevent, diagnose or treat illness (Howitt et al., 2012) (see Chapter 2). They cluster healthcare technologies into six categories: drugs and biological products, medical devices, medical and surgical procedures, support systems, and organisational systems. Even if very different from the most common healthcare technologies, according to Howitt's definition, as well the one of the WHO (Kwankem et al., 2001) (see Section 2.1.2), the HEG technology is clearly a *healthcare technology*. It was invented with the intention to prevent the spread of malaria to humans, by lowering the number of mosquitoes which are vectors for the *Plasmodium* parasite. Given its nature, it can be further categorised as *biological product*.

Target Malaria's technology is centred on a 'hard technology' (the GM *Anopheles* mosquitoes), but has a great deal of soft technology and knowledge wrapped around it (i.e. how to create and maintain transgenic mosquitoes, how to deploy them, how

to monitor their impact and so on). This technology is therefore a part within a *complex technology system* (Greenhalgh et al., 2004b), bringing together scientists from various disciplines, healthcare experts, community engagement and risk assessment specialists, policy makers and regulatory bodies. It is therefore also crucial that the adoption and diffusion of such an innovation is correlated with organisational and system's changes.

Further, according to the model by Henderson and Clark (see Chapter 2), innovation can be characterised and classified by looking at the degree of 'innovativeness' that it incorporates (Henderson and Clark, 1990). They consider the amount and type of knowledge needed for the innovation to occur. The knowledge type is divided into two parts: the component knowledge and the architectural or system knowledge. Even if vector control and SITs are widely used and understood, Target Malaria's technology is innovative in terms of both component knowledge (engineering of HEGs and CRISPR/Cas9 systems) and architectural knowledge (clarification of target genes as well as use of HEGs or CRISPR/Cas9 systems to induce sterility in different ways in specific mosquito strains). It can therefore be considered a *radical innovation*.

6.1.4 Target Malaria's new technology development pipeline

Chapter 2 describes how the invention, commercialisation and adoption and diffusion phases of the innovation process are often non-linear, with feedback between phases resulting in an iterative form of new product development (Cooper, 2001). This is especially the case with highly complex and/or radical innovations. This is especially the case for the gene drive transgenic mosquito technology of Target Malaria. The complexity of the R&D process means that development work, deployment and adoption are intrinsically interlinked.

The aim of Target Malaria's scientists is to create one or more self-sustaining strains of modified malaria mosquitoes in order to spread the modification throughout the specific population relatively quickly (over a period of a few years) and easily (the mosquitoes themselves do the work). Given that such an innovation is

unprecedented and the consequences of such a technology are unknown, intermediate constructs that will limit the potential spread of the genetic trait in a local mosquito population have been designed. Testing of these more conservative intermediates will contribute important information to the development and safety testing of the self-sustaining version. In fact, it is a prerogative of the consortium to ensure that the technology developed is safe, efficient, and is locally accepted by both, regulators as well as the local population and each of these.

Hence, the whole product development pipeline was adapted to such a research design and Target Malaria's technology is currently being developed in 3 phases of increased complexity (Figure 17): self-limiting sterile males, self-limiting male bias, and self-sustaining male bias or self-sustaining target knock-out. Each of these phases then further entails different stages of technological development.

Phase 1 is based on the development and testing of *self-limiting, functionally sterile male mosquitoes*. In this technology, sterility is induced by a genetic modification, which prevents egg development after mating and fertilization. In this case, the genetic modification cannot be passed from generation to generation as the eggs cannot develop. A similar principle has already been adopted as an intervention for eradication of agricultural pests such as screw worm flies and for the control of fruit flies (i.e. Medfly) via Sterile Insect Technique (SIT) (Robinson, 2002a, Robinson, 2002b). The SIT technology, however, is less advanced, as it produces sterile males by ionizing radiation (Helinski et al., 2009). However, due to the innate sterility, these mosquitoes will not be able to spread and will disappear from the population quickly (i.e. a couple weeks) after release. This first stage is purposefully an initial step towards the longer term research. In fact, this self-limiting technology is an intermediate phase that will be tested to transfer knowledge and build operational capacity for further development and deployment of the technology, but will not be used released as a tool for vector control as not deemed appropriate.

Phase 2 relies on *self-limiting, fertile males producing male-biased offspring*. This technology aims to reduce the number of female offspring through a genetic modification located on one of the autosomes, resulting in a biased ratio of males to females born. This modification, although initially passed from generation to

generation of mosquitoes, will eventually be selected out of the population. This will lead to a gradual disappearance of the altered genetic trait from the population, resulting in a self-limiting product. These self-limiting mosquitoes are considered an intermediary technology to test the safety and efficacy of Target Malaria's final technology. In fact, the purpose of small-scale releases of this technology is to learn how the modified mosquitoes spread spatially and how the modification can be transmitted from one generation to the next. It may be useful for malaria control, but this will need to be based on the results achieved.

The third phase of development and testing is based on the development of two different types of *self-sustaining male bias* or *target knock-out genetically modified mosquitoes*. Both these technologies have not yet been fully developed, but these two alternative strategies are complementary and could be used either in combination or alone.

Self-sustaining fertile males producing male-biased offspring are GM mosquitoes producing mainly male offspring. This technology aims to reduce the number of female offspring through a genetic modification located on the allosomes (Y chromosome), resulting in a biased ratio of males to females born. These males carry the modification on the Y chromosome and hence this modification is able to spread and persist over time in a local mosquito population. In fact, the modification would be able to spread to most or all of the target *Anopheles* population in the release area. As the mosquito population becomes increasingly male, lack of mating opportunities would cause the number of only the targeted *Anopheles* mosquito species, including malaria-transmitting females, to decline.

Self-sustaining female mosquitoes with reduced fertility technology are GM mosquitoes based on the population-wide gene knockout of female fertility genes (see Section 6.1.1). In this case, female GM mosquitoes which carry only one copy of the modified gene are fertile, while those with two copies of the modified gene are sterile. As the gene drive element increases in frequency in the population, so does the probability of the offspring receiving a copy of the modified gene from both parents and hence being sterile. The lack of offspring from these females leads to an overall reduction in the population of malaria mosquitoes. Also in this case, over

time, i.e. over the course of several years, the modification would spread to most or all of the targeted *Anopheles* population in the area.

These technologies would see a phased roll out, including small scale releases to assess whether the modification is spreading in the way that it is expected to, and whether it maintains its characteristics as it spreads. Further trials may then be performed to measure mosquito reduction more directly before going to national deployment.

Both self-sustaining mosquito strains are expected to be innovative and solid malaria elimination tools and will represent a new, innovative, low cost, and sustainable technology expected to provide long term reduction in mosquito numbers over large areas. In fact, the release of these self-sustaining mosquitoes is forecasted to lead to a significant reduction in the incidence of malaria cases in those areas.

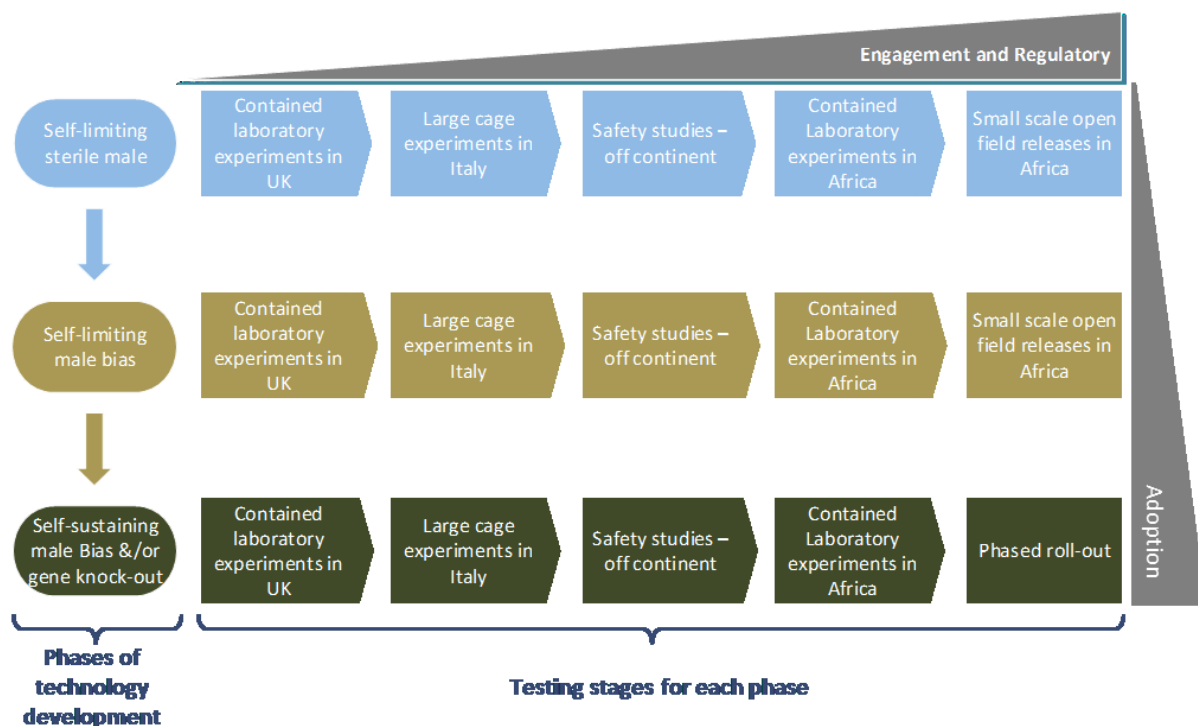


Figure 17: Visualisation of technology development phases of Target Malaria's technology.

A more detailed overview of the process can be found in the Appendix (Section 12.8).

Based on: Target Malaria (2016b).

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As mentioned above, each of these phases of technology development is subdivided into different development and testing stages. For each of the technologies the creation of the transgenic strains, as well as the proof of principle in small cages, is performed at Imperial College London and clustered under contained laboratory experiments. Once initial testing in the laboratory is deemed successful the technologies(s) transition to a state-of-the-art facility with large climatic chambers in Italy. Here the same tests are repeated in large cages which accurately represent the natural environment of these mosquito strains as proof of concept. Furthermore, the large cage conditions permit further experiments, like strain evaluation and basic life history, larval survival tests, competitive mating assessments and other cage trials. Once these efficacy tests are completed, the approved strains are sent to specialised laboratories in the USA for safety studies. These include basic molecular, genotypic, physiological and behavioural characteristics of the transgenic strain relative to a non-transgenic comparator strain, as well as studies of vector competence, insecticide resistance, and disappearance of the self-limiting transgene. These are essential to ensure the tests performed in disease endemic countries are safe and to guarantee that the final technology offers a long term, sustainable and cost effective method for malaria control.

Once a strain is deemed successful, it is transferred to African partner institutions for further testing. This process is subject to regulatory approval by the regulatory bodies of the receiving country. The transfer to the disease-endemic countries will be approached in stages to ensure safety and to build confidence of the national regulatory agencies and the community at large. Prior to each step in the process country, specific regulatory approvals will be sought.

At present, three African Research Institutions are part of Target Malaria's consortium: the 'Institut de Recherche en Sciences de la Santé' (IRSS) in Burkina Faso, the 'Malaria Research and Training Center' (MRTC) in Mali, and the 'Uganda Virus Research Institute' in Uganda. In each of these institutions laboratories have been built and equipped so that the modified mosquitoes can be developed, tested and reared locally.

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The in-country testing will be performed in two phases. First the strains will be imported for contained laboratory experiments. These include, amongst other, the transfer of the transgene into the local genetic mosquito background as well as the measurement of the effect of the transgene on larval development to adult mosquitoes and on host attraction (competitive mating). Once the proof of concept is validated also in the local mosquito colonies, regulatory approvals for small scale open field releases will be sought leading to an eventual phased roll-out of the final self-sustaining technology. The extent and details of these will be based on the technology to be tested and the data to be collected.

As of now (December 2016), both the self-limiting sterile males and male bias mosquitoes have been generated at Imperial College London. Both stages have been subjected to testing in small cage laboratory studies in London, with good results. The sterile male technology has also been tested in the large-cages in Italy and all studies outside Africa have been successful. The Burkinabé regulatory authorities have approved the import for contained studies of this mosquito strain, leading to the first ever importation of transgenic mosquitoes to Africa in November 2016. The next phase will be testing the technology in contained laboratories at IRSS in Burkina Faso. The self-limiting male bias mosquito strains are now being bred in the large-cage, contained laboratories in Italy and, based on the preliminary results, a leading strain should be soon sent for off-continent safety studies in the USA. Furthermore, scientists from Imperial College London are developing various strains of the self-sustaining technology.

At present, therefore, the project has just concluded for Burkina Faso and is in the process of laying the ground in Mali and Uganda for a first step in the adoption process of the sterile male technology by the regulatory authorities. As discussed in Chapter 2, adoption of complex health technologies will be influenced by a range of factors relating to the technology itself and its characteristics, including the evidence of its impact, the attitudes and feelings of the adopting agencies – whether individuals or institutions – towards the technology, and wider contextual factors. This is therefore a crucial stage in the adoption decision and subsequently implementation (Greenhalgh et al., 2004b).

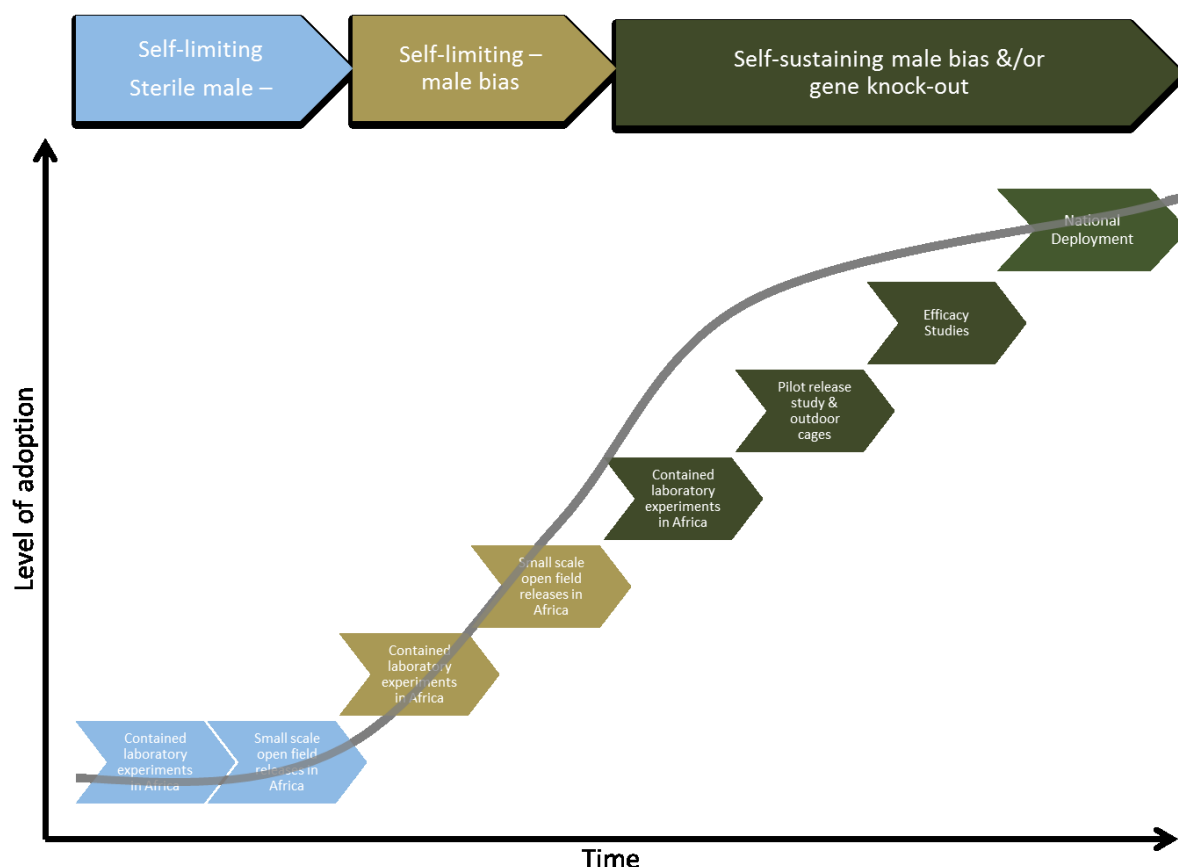


Figure 18: Product development phases and stages of Target Malaria's technology in Africa and the relative technology adoption level.

Based on Target Malaria (2016b).

It is also clear that Target Malaria's product development process is a complex and non-linear process. In fact, the progression within the various technology development phases and the sub-stages of technological development are highly interlinked, with the in-country adoption process leading to a very intricate, multifaceted, and non-linear complex process. This is enhanced by the technological complexity behind gene drive transgenic mosquitoes.

Nevertheless, despite the non-linear NPD process, and wider the controversial perceptions related to GM innovations, Target Malaria's technology has the prerequisites to be a valid candidate to fill the gap which existing malaria eradication technologies have failed to address (Windbichler et al., 2011). An effective implementation, diffusion and scaling up process of this technology could be a critical success factor in the fight against malaria. In order to ensure a successful implementation of the project, though, it is crucial to better understand

this adoption process within the local context as well as the underlying dynamics behind it.

Target Malaria product development pipeline in Burkina Faso

As elucidated in Chapter 4.4.4, the context in which technologies are adopted is a crucial element of the complex process behind its uptake. Hence, it was important to understand how and when Target Malaria's technology will be deployed in Burkina Faso in order to understand the key dynamics behind the adoption process.

As described in Figure 19, Burkina Faso's product development pipeline overlaps with the general Target Malaria R&D pipeline. It is important to note that Burkina Faso has taken a leading role in the development of the technology, with a reasonably strong regulatory system regarding GM technology (see Chapter 5). As mentioned above, it has recently become the first country in Africa to import the sterile male GM mosquito strain for contained use experiments in November 2016. The contained laboratory studies have just commenced and will take approximately a year. The data from these studies will be then submitted to the regulatory authorities and if approved a small-scale, geographically confined open field release will take place (planned July 2018 to February 2019). This step will be crucial to transfer knowledge, build operational capacity, and gain local community support for the further development and deployment of the next phases of the technology.

Once the data from the first field releases has been analysed, the team plans to submit an application for open field release for the self-limiting male bias to gain approval in March 2020. This will cover both the contained laboratory experiments (precautionary measure) as well as the small-scale releases, which are planned to be performed by June 2021.

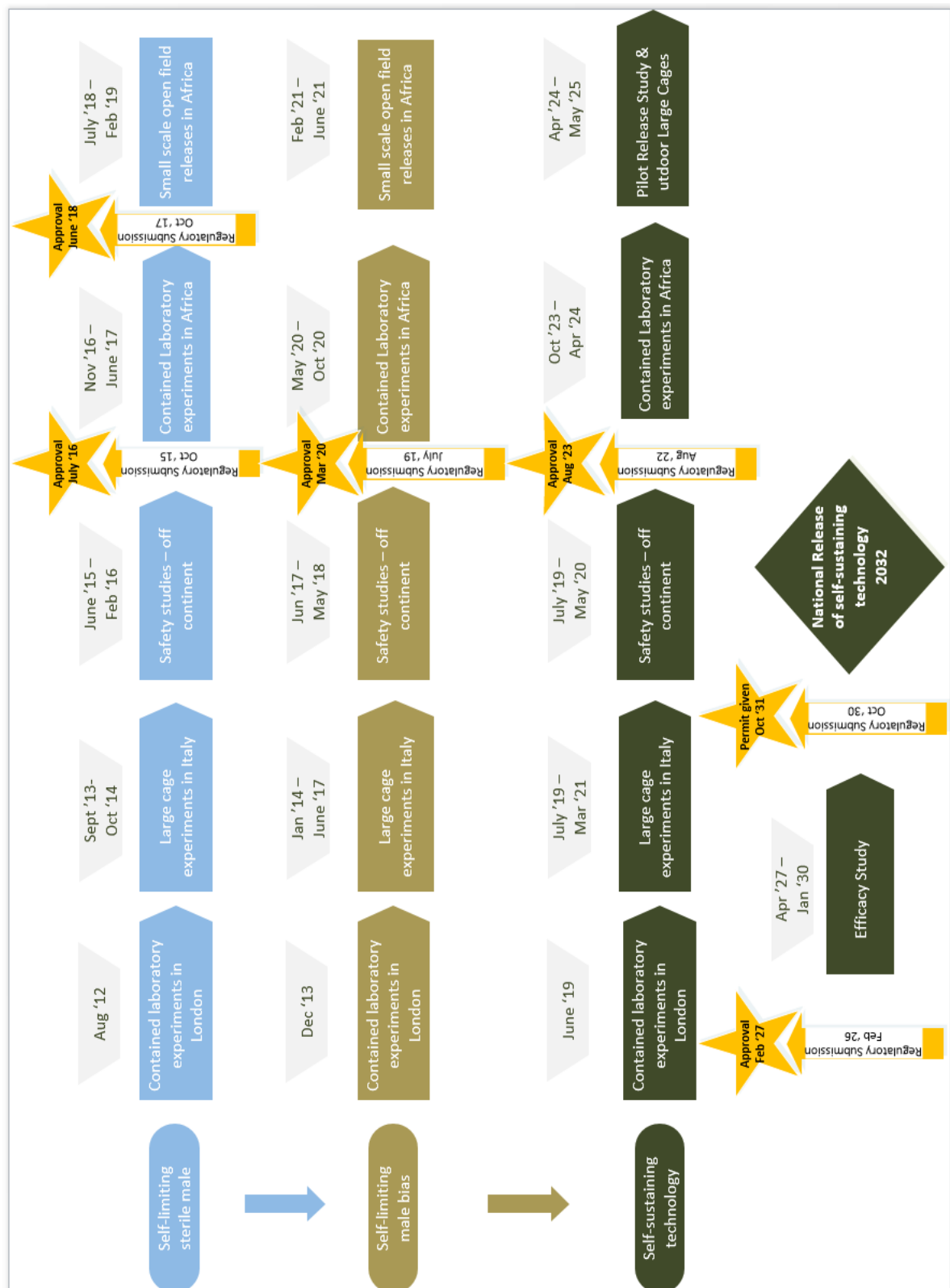


Figure 19: Visualisation of technology development phases and corresponding timelines of Target Malaria's technology in Burkina Faso.

Based on Target Malaria (2016b).

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Once this phase is ended the same pathway will be followed for the self-sustaining technology, preliminarily in August 2022. In this case, though, the small-scale releases will be used as concrete pilot release studies and a phased development followed by a larger efficacy study which will require a separate regulatory approval. It is important to note, that Target Malaria's aim is to receive not only regulatory approval, but also a social licence to operate based on public acceptance, and is hence working with stakeholder engagement specialists on the best way to ensure this will be made possible through a series of public consultations. The aim is for Target Malaria is to have a technology ready for national release in Burkina Faso by 2032, in line with the UN's malaria eradication timelines.

7 Context and health system analysis of Burkina Faso

Chapter 7 analyses both the context and the health system of Burkina Faso in order to gain important insights for the introduction of complex health technologies like GM mosquitoes within that system. Given the intrinsic complexity of health systems highlighted in Chapter 2, it is essential to fully understand the structure of the local health system and the context within which it is embedded before deploying a new technology. Given the type of technology in question the author decided to focus on demographic, epidemiological, socio-cultural, economic, political, and ecological landscape that could impact the introduction of GM mosquitoes surrounding the Burkinabé health system, before exploring the factors influencing the introduction of technologies for malaria control and elimination in Chapters 8 and 9. Furthermore, the technological advancement of the country and the legal and regulatory factors leading to the governance of GMOs in Burkina Faso were also analysed.

Aim was to outline the overall landscape within which Burkinabé malaria elimination programmes have been developed and the factors which influence the introduction of new technological approaches such as GM mosquitoes. The analysis in the chapter also enabled the author to map out the stakeholder landscape shaping malaria policy, programmes and technologies, and develop the topic guide for the qualitative research and system dynamics modelling (Chapter 9).

7.1 Methodology

The framework used for the analysis of the health system and context within the PhD study draws on the framework by Atun et al. (2013) and is further complemented by the approaches of Frenk (1994), Hsiao (2003), the WHO (2000b), and others (Roberts et al., 2004, Samb et al., 2009, Atun et al., 2006). It takes a systems approach (Atun, 2012, Swanson et al., 2012) to analyse the contextual factors and health systems functions that interact to influence achievement of health

system goals and health systems objectives (Atun et al., 2013), including the elimination of malaria.

In the framework, the *context* refers to the interdependencies between the demographic, epidemiological, political, legal and regulatory, economic, socio-cultural, technological, ecological and other factors. Together, these factors all have the potential to impact on the health system and the scope for interventions within it (Atun et al., 2013). For example, demographic changes, historical precedents, and socio-cultural norms (which provide cognitive or normative legitimacy for policies) can strongly influence health system reforms, while critical events such as regime change or natural catastrophes can create external shockwaves and create opportunities for changes within a health system. The achievement of *health system goals* can be broadly clustered under population health, financial protection, and user satisfaction (Atun et al., 2013). Health systems also have *objectives* such as the achievement of equity, efficiency, effectiveness and responsiveness (Atun et al., 2013). Additionally, the framework identifies four main *health system functions*: 'governance and organisation', 'financing', 'resource management' and 'service delivery' (Atun et al., 2013).

Given the scope of the PhD study it was not deemed as necessary to discuss in detail all these elements of the health system, but the focus was set on the contextual factors and health system functions that relate specifically to policies for malaria eradication and the introduction of GM mosquitoes.

7.2 Results

7.2.1 Burkina Faso context analysis

Demographic context

With a population of 18.6m people (rank 19/54 in Africa) and a surface area of 272,967 km² (rank 29/54 in Africa), Burkina Faso is one of the fastest growing African countries, with an average annual population growth rate of 2.9% (2010-2015) (UNdata, 2013). An average of 5.7 live births per woman (2010 to 2015 range) (UN Data, 2016) means Burkina Faso's fertility rate is one of the highest in the world (rank 6/225) and is only inferior to Niger, Burundi, Mali, Somalia and Uganda (Central Intelligence Agency, 2016).

The population structure of Burkina Faso (Figure 20) shows a very young society with almost half of the population (45.2%) under 14 years of age and, as a result, an extremely high total dependency ratio of 92.2% (87.6% youth dependency ratio, 4.6% elderly dependency ratio) and low potential support ratio (21.7% - 2015 est.) (Central Intelligence Agency, 2016). This development is driven by a declining mortality rate combined with a consistently high fertility rate. Furthermore, predictions show that even if fertility were to be substantially reduced, today's large cohort entering their reproductive years would further drive high population growth for the foreseeable future (Central Intelligence Agency, 2016).

The Burkinabé population remains largely rural with only 29.9% of the total population (2015 est.) living in urban areas (Central Intelligence Agency, 2016, UNdata, 2013). Nevertheless, there is a rapid and increasing urbanisation with an annual average urban population growth rate of 5.9% (2010-2015) (Central Intelligence Agency, 2016, UNdata, 2013).

A large part of the Burkinabé male labour force migrates annually to all neighbouring countries for seasonal employment (Central Intelligence Agency, 2016). This has traditionally been a way of life for Burkinabé people, but seasonal migration being is being increasingly replaced by longer stays abroad (up to two years) (Central Intelligence Agency, 2016). There is also migration into Burkina Faso from Ivory Coast, Ghana, and Mali, where the populations often share common

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ethnic backgrounds with the inhabitants of Burkina Faso (Central Intelligence Agency, 2016). Additionally, in the light the recent geo-political struggles, Burkina Faso has become a destination for refugees (Central Intelligence Agency, 2016).

The demographic data from Burkina Faso is archetypical for developing countries in the so-called demographic transition. This term denotes changes in the age structure of a population, which is often related to a sustained fall in mortality and fertility rates (Coale, 1974, Lee and Mason, 2006). Usually the fall in mortality tends to precede fall in fertility (Coale, 1974). This lag leads to a population growth called demographic wave (Coale, 1974). As a consequence, demographic transitions produce a significant increase in the size of the working-age population compared to the dependent population (Coale, 1974). In the same period, there is also normally a shift from a rural, agrarian based population to an urban, industrialized population (Lee and Mason, 2006).

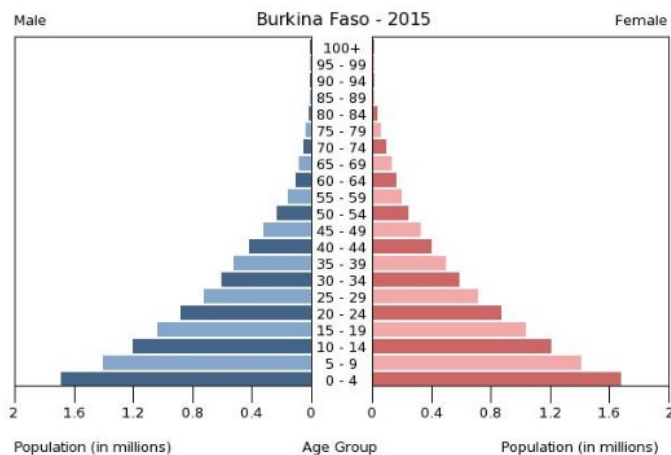


Figure 20: Population pyramid of Burkina Faso

Males shown on the left and females on the right.

Source: Central Intelligence Agency (2016).

Epidemiological context

Life expectancy at birth indicates the number of years a new-born infant would live if prevailing patterns of mortality at the time of its birth were to stay remain constant throughout its life. In Burkina Faso, life expectancy at birth (Figure 21) has risen dramatically since 1990 for both men (54.8 years in 2015) and women (56.7 years in 2015), with actual observed averages of 60.0 years for men and 61.9 years for women (Institute for Health Metrics and Evaluation, 2016a). This has slightly closed the gap with the global average (71.4 years in 2015) (WHO, 2016b) and is a remarkable achievement given the continuous political instability of the country in the past 15 years.

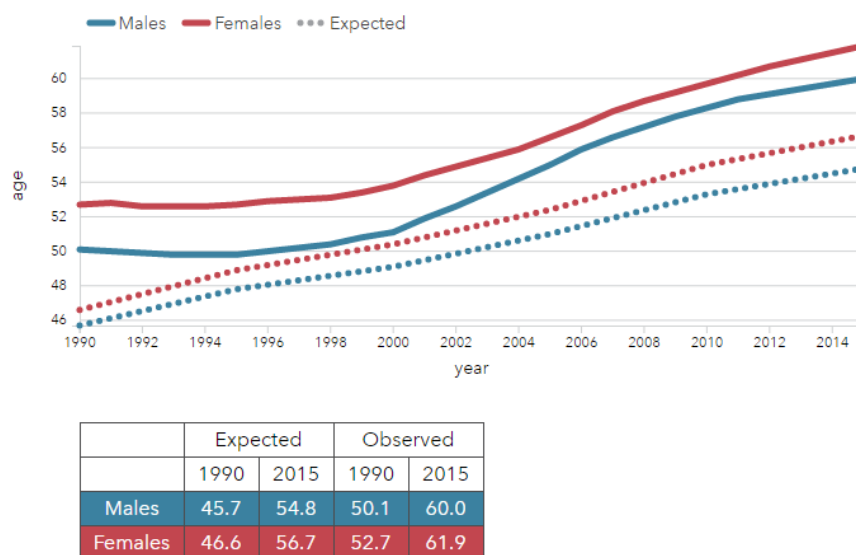


Figure 21: Burkina Faso's life expectancy at birth from 1990 to 2015.

Source: Institute for Health Metrics and Evaluation (2016a).

Country statistics furthermore show that Burkina Faso has achieved a significant reduction in infant and child mortality rate (down by ca. 52% from 1990 to 2013) and ranks below the average of the West Sub-Saharan Africa countries (Institute for Health Metrics and Evaluation, 2016c). This decrease is mainly driven by improved health care, hygiene, and sanitation (Central Intelligence Agency, 2016). However, child mortality 74 deaths per 1000 live birth (2016 estimate), amongst the top 10 in the world (rank 9/225) (Central Intelligence Agency, 2016). In addition, maternal

mortality is high. Between 1990 and 2004, maternal mortality saw a dramatic increase, peaking at 410 deaths per 100,000 live births. By 2016, though, the maternal mortality rate had fallen to 371 deaths per 100,000 live births, but this was still higher than the level in 1990 (Central Intelligence Agency, 2016, Institute for Health Metrics and Evaluation, 2016d). Haemorrhage, abortion complications, and other direct birth related issues are the three major causes of maternal death (Institute for Health Metrics and Evaluation, 2016d).

Despite great achievements attained in the reduction of the burden of disease, Burkina Faso is still plagued by communicable diseases. Even with a 46.0% decrease since 2005, malaria remains the major cause of death across all ages for both sexes, accounting for 20.2% of all deaths in the country in 2015 (Institute for Health Metrics and Evaluation, 2016b). This is followed by lower respiratory tract infections (10.6% of total deaths in 2015) and diarrheal diseases (7.8% of total deaths in 2015) (Institute for Health Metrics and Evaluation, 2016b). The biggest success since 2005 has been achieved in the battle against HIV/AIDS, which has seen a 77.1% reduction in deaths caused by the disease (Institute for Health Metrics and Evaluation, 2016a).

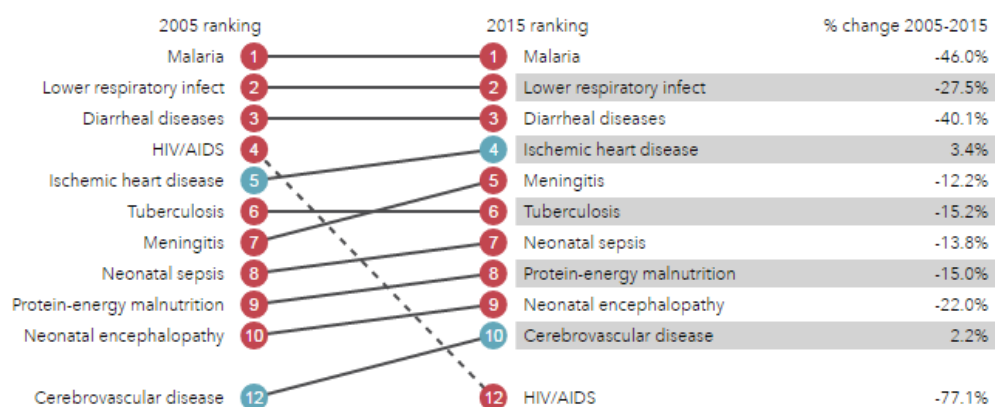


Figure 22: Top 10 causes of death by rate in 2015 and percent change, 2005-2015.

In red: communicable, maternal, neonatal, and nutritional diseases. In blue: Non-communicable diseases.
Based on: Institute for Health Metrics and Evaluation (2016a).

The major causes of death and disability in Burkina Faso are communicable diseases, maternal and neonatal diseases. The most significant underlying causes of disability-adjusted life years (DALYs) in 2015 were the same as for mortality: malaria,

lower respiratory infections, and diarrheal diseases (Institute for Health Metrics and Evaluation, 2016a, Institute for Health Metrics and Evaluation, 2016b). Although these have seen a remarkably high reduction since 1990 (up to almost -45%), they still place a huge toll on the health of the Burkinabé people (Institute for Health Metrics and Evaluation, 2016b). The main risk factors that drive most deaths and disabilities are of behavioural nature with malnutrition, unsafe sex and alcohol and drug use at the forefront (Institute for Health Metrics and Evaluation, 2016b). This is followed by environmental risks comprising of air pollution, occupational risks and WaSH (water, sanitation, and hygiene) (Institute for Health Metrics and Evaluation, 2016b).

The epidemiological pattern observed in Burkina Faso is therefore typical for developing countries in the demographic transition. Given the current devastating disease and poverty levels, urgent reforms to improve the health situation are therefore required.

Economic context

Burkina Faso's economy is mainly characterised by its extremely limited natural resources, leading to high poverty levels and a gross per capita income of just 615 USD in 2015 (World Bank, 2016a). Its economy relies principally on agricultural production and subsistence farming, which suffers from inadequate rainfall (Central Intelligence Agency, 2016). About 80% of the working population is employed in the primary sector, with cotton being the country's most important cash crop (World Bank, 2016a, Central Intelligence Agency, 2016). Gold exports have become more important in recent years, accounting for about three-quarters of the country's total export revenues in 2015 (Central Intelligence Agency, 2016). This makes the country's economic growth and revenue very dependent of the global prices for those two commodities. Nevertheless, an increasing number of Burkinabé have moved into the manufacturing sector, partly driven by urbanization.

The Burkinabé economy has experienced a slowdown in the rate of economic growth, with the annual GDP growth rate falling to 4% in 2014/15, compared to an

average of above 6% over the previous decade (World Bank, 2016a). This is due to a combination of several factors, including the recent socio-political instability on economic activity and public finances, as well as exogenous shocks associated with the falling price of raw materials and the impact of the Ebola pandemic in the Western Sub-Saharan African region (World Bank, 2016a). Additionally, this recession has had drastic decline in public investment as consequence, which was also heavily reflected in the healthcare sector (World Bank, 2016a).

Unemployment is widespread (Central Intelligence Agency, 2016) and the recession has led to repeated public protests over the high cost of living, corruption, and a number of socio-economic issues. Burkina Faso is therefore heavily reliant on support from technical and financial partners, especially of the World Bank and the IMF (World Bank, 2016a, International Monetary Fund, 2015).

Despite the efforts of the Burkinabé government to alleviate poverty, 40.1% of the population still live below the national poverty line (World Bank Data, 2016b) and the country is plagued by high inequality (World Bank Data, 2016a). Burkina Faso is also near the bottom of the (183/188) of the UNDP Human Development Index and remains on the United Nations least developed countries (LDCs) list (UNDP, 2016, United Nations Committee for Development Policy, 2016).

Despite a gross enrolment rate of 84% at primary school level, 39.7% at secondary education and 14% for upper secondary education in 2014 (World Bank, 2016a), the literacy rate for young people is only 36% (Central Intelligence Agency, 2016), lower than the average rate of over 70% for Sub-Saharan Africa (World Bank, 2016a).

Combining all of the factors above with the country's limited natural resources, a fragile soil, a high population density, and a highly unequal distribution of income, the economic prospects for Burkina Faso's large working-age population remain extremely unstable with serious development challenges ahead (UN-OHRLLS, 2016). Nevertheless, in July 2016 the Government adopted a new development programme for inclusive growth, the 2016-2020 National Economic and Social Development Plan (*Plan National du Développement Économique et Social*, PNDES) (Ministère de l'Economie et des Finances (MEF), 2016). This set out three goals to (a) increase cumulative growth in per capita income to reduce poverty, (b) strengthen

human capacities, and (c) meet basic needs within an equitable and sustainable social framework (Ministère de l'Economie et des Finances (MEF), 2016). One of the pillars supporting the plan is reform of institutions and modernisation of the administration.

If successfully implemented, the changes envisioned by the PNDES 2016-2020 have the potential to make a major impact on the social determinates of health. Firstly, increasing the per capita GDP by 2020 would have a positive impact on the available health budget, especially if coupled with a transformation of the health system. Secondly, if the aims of modernizing agriculture and improving the quality of livestock are met, there are opportunities to directly improve health outcomes goals, including the eradication of malnutrition. More efficient food production due to modernized agricultural technique and equipment will decrease food insecurity and lead to a healthier diet of higher-quality, nutrient-rich foods. This could help alleviate the health burden that arises from under- and malnutrition.

Political context and governance

From the time the Republic of Upper Volta gained its independence from France in 1960, the country has seen frequent periods of political unrest and repeated military coups (BBC News, 2016). The country was renamed Burkina Faso in August 1984 by President Thomas Sankara (WorldAtlas, 2012, BBC News, 2016). His leadership was characterised by the adoption of radical left-wing policies (BBC News, 2016), but Sankara was killed in a coup led by his close advisor, Blaise Compaore in 1987. Compaore governed Burkina Faso until October 2014, when he was forced to step down following violent, popular protests against his efforts to amend the Constitution's presidential limit in order to prolong his presidential mandate (BBC News, 2016, Central Intelligence Agency, 2016). Despite the fact that he had been elected democratically several times and had brought democracy back to the country, Compaore's leadership was marked by economic grievances, alleged human rights violations, UN allegations of arms smuggling to rebels in Sierra Leone and Angola, and civil unrest (BBC News, 2016). Between October and November 2014, the military took charge of the country, but a framework for an interim government

was subsequently adopted (Central Intelligence Agency, 2016). An interim administration was put in place, prior to the planned presidential and legislative elections. A further failed coup attempt led to delays in holding the elections, but in November 2015 Roch Marc Christian Kabore of the *Mouvement du peuple pour le progrès* (MPP) ('People's Movement for Progress') was elected president (BBC News, 2016, Central Intelligence Agency, 2016). The MPP also won a parliamentary majority which was crucial for the political sustainability of the Government (World Bank, 2016a). Municipal elections were held in May 2016 (World Bank, 2016a).

Since then the political situation seems to have stabilised and Burkina Faso is now a parliamentary republic with a Prime Minister (Yacouba Isaac Zida) as the Head of the Government and a President (Roch Marc Christian Kabore) as Chief of State (Président du Faso) (Encyclopædia Britannica, 2016). The President is elected directly by a popular vote in a multiparty election for a five-year mandate and may serve up to two terms (Encyclopædia Britannica, 2016, Somé, 2016). He has the right to appoint the Prime Minister (Encyclopædia Britannica, 2016, Somé, 2016).

The Burkinabé constitution postulates that Burkina Faso is a democratic, unitary and secular state, and consecrates the separation of powers (Encyclopædia Britannica, 2016, Somé, 2016). The executive power is exercised by both, the President and the Government, while the legislative power is conferred to both the Government and the unicameral National Assembly (Assemblée Nationale) (Encyclopædia Britannica, 2016, Somé, 2016). The relationship between the executive and the legislative branches is characterized by the fact that the National Assembly can engage Government's responsibility by passing a vote of 'no confidence', while, in return, the Government can dissolve the National Assembly (Somé, 2016).

Administratively, Burkina Faso is subdivided into 13 regions, 45 provinces, 350 departments, 351 communes (49 urban communes and 302 rural communes), and 8228 villages (Observatory, 2012). The regions and the communes are financially autonomous, and the regions, the provinces, the departments and the villages are single administrative units (Observatory, 2012).

Socio-cultural context

Burkina Faso is a melting pot of many different cultures and ethnic groups. Over 60 ethnic groups inhabit the country (Our Africa, 2015). The Mossi are the largest ethnic group present in the country and make up approximately half the population (52.5% in 2010) (Central Intelligence Agency, 2016, Our Africa, 2015), having absorbed a variety of other ethnic groups over the centuries (Encyclopædia Britannica, 2016). The Fulani are the second largest ethnic group, but only represent 8.4% of total population in 2010 (Central Intelligence Agency, 2016). Regardless of their ethnic origin, citizens of Burkina Faso are collectively known as Burkinabé and identify themselves as such (Encyclopædia Britannica, 2016). As the population needs to be geographically flexible for work-related reasons, the Burkinabé population is used to intermixing and a strong sense of community and mutual support has evolved (Our Africa, 2015). Burkina's people live in relative harmony compared to most neighbouring countries which have experienced civil wars and racial hatred in recent years (Encyclopædia Britannica, 2016).

This multi-ethnicity is also reflected in the variety of languages and dialects spoken, with an estimated 68 individual languages being currently spoken (Lewis, 2013). The official national language is French (Lewis, 2013), which was introduced during the colonial period. Mossi (Mossi: Mòoré) is the most predominant native language and is spoken by about 40% of the population (WorldLanguage, 2013), mainly in the central region (Encyclopædia Britannica, 2016).

Music and film play a major role in the Burkinabé culture. The country has its own national film-making industry which dates back to the 1960s; Ouagadougou is regarded as the African capital of cinema and hosts the Panafrican Film and Television Festival of Ouagadougou (Our Africa, 2015, FESPACO, 2016). Music plays also a vital role in the country's culture and many children learn to play local instruments early on (Our Africa, 2015). Given the culture of oral tradition, most of the local customs are also passed on from generation to generation with the aid of musical storytelling. This way of passing on messages is leveraged by the Government and the health system in rural areas. For example, there has been widespread use of the Grigri (traditional storyteller) to announce the arrival of

vaccination teams to the villages, or for the explanation of public health campaigns. Role-play theatre has also been used extensively in the HIV/AIDS campaigns.

Data on religious affiliation are only approximate, as Islam and Christianity are consistently practiced in parallel with indigenous religious beliefs which are deeply rooted and interlinked to the various ethnic groups (State, 2012). Roughly 61% of the population practices Islam (State, 2012). The government estimates that 23% of the inhabitants are Roman Catholic, 7% are believed to follow exclusively indigenous beliefs, and 6% are members of various Protestant denominations (Central Intelligence Agency, 2016). Different religions are accepted and tolerated by the Burkinabé and often different family members belong to separate religious groups (Encyclopædia Britannica, 2016).

Many Burkinabé also hold traditional animist beliefs in spirits. This poses challenges for healthcare, as traditional healing practices are still very widespread. Traditional healers are common and tend to be favoured over visits at primary health facilities. Recently, though, the Ministry of Health has started developing a programme in order to integrate government-recognised Traditional Health Practitioners (THPs) as Primary Healthcare (PHC) providers and for the integration of traditional medicine into the national health systems. This strategy has long been endorsed by the WHO for the treatment of different diseases to ensure appropriate, safe and effective use of traditional medicine (West African Health Organization et al., 2010).

Despite the high levels of tolerance in the country, society has been historically male dominated, and there different forms of violence against women are still prevalent (UN Women, 2016): 76% of girls and women aged 15 to 49 years are victims of female genital mutilation/cutting (UN Women, 2016, UNICEF, 2013) and 52% of women aged 20 to 24 were first married or in a sexual union before age of 18 years (UN Women, 2016, UNICEF, 2013). Furthermore, women still suffer from high rates of sexual violence at home (UN Women, 2016).

Ecological context

Positioned at the geographical heart of West Africa, Burkina Faso is a landlocked country with a surface area of about 272,967 km² (slightly larger than Colorado, USA), out of which only 400 km² are of water surface (Central Intelligence Agency, 2016). The terrain is mostly flat to dissect with some undulating plains and some hills in the western and the southeast regions of the country (Central Intelligence Agency, 2016) and characterised by the lateritic (red, sandy, iron-bearing) layer of rock that covers the underlying crystalline rocks (Encyclopædia Britannica, 2016). The territory is incised by the country's three principal rivers: the Black Volta (Mouhoun), the Red Volta (Nazinon), and the White Volta (Nakambé) (Central Intelligence Agency, 2016). The highest point of Burkina Faso is Tena Kourou which lies 749 m above sea level, while the lowest point is the Mouhoun (Black Volta) River at approximately 200 m above sea level (Central Intelligence Agency, 2016).

The capital, Ouagadougou, is located in the centre of the country, which is neighboured by 6 countries: Benin, Cote d'Ivoire, Ghana, Mali, Niger, and Togo (Observatory, 2012, Central Intelligence Agency, 2016).

The climate is predominantly sunny, hot, and arid with 4 distinct seasons (Encyclopædia Britannica, 2016):

- A rainless and cooler season from mid-November to mid-February with average temperatures around 20°C;
- An extremely torrid season from mid-February to June, when maximum temperatures rise to over 40°C in the shade and a frequent red-dust charged, north-easterly trade wind called the Harmattan blows from the Sahara Desert over Burkina Faso;
- A brief and scarce rainy season, which lasts from June to September;
- An intermediate season, which lasts from September until mid-November.

The country is sub-divided in two principal climate zones: the Sahelian zone in the north and the Sudanic zone in the south (Encyclopædia Britannica, 2016). The former consists of very unfertile semiarid savannah, characterized by irregular three

to five months of rainfall, while in the latter zone the climate becomes increasingly tropical wet-dry, with a larger variability of temperature and rainfall (Encyclopædia Britannica, 2016). The annual rainfall varies from less than 250mm in Sahelian zone to roughly 1,000mm in the southern part of the Sudanic zone (Encyclopædia Britannica, 2016).

The unstable climatic conditions as well as the recent droughts and desertification issues not only severely affect the country's economy, which relies predominantly on agricultural and farming activities, but also have direct and indirect effects on food security, with major impact on the health and wellbeing of the Burkinabé people.

Furthermore, despite the harsh climatic conditions, the prevalence of the main vectors of malaria and the Plasmodium parasite is extremely high throughout the entire year (Oxford Big Data Institute and University of Oxford, 2016), causing malaria to be the major cause of death and hospitalisation in the country .

7.2.2 Burkina Faso's health system analysis

Some of the progress in the health of the country's population can be ascribed to increased government expenditure on healthcare (UNHCO, 2012). The government's per-capita expenditure on health has increased to approximately 40 USD/year in 2011, which represented an estimated 4.1 % of GDP (UNHCO, 2012).

Nevertheless, the political instability that has plagued the country has meant that many health-related bills and policies with legally binding and enforceable instruments have lingered within the legislative system without being signed into law. The Minister of Health, Dr Smaila Ouédraogo, is now leading an agenda focused on health promotion and disease prevention strategies, with universal health coverage as a major goal (Ministère de la Santé du Burkina Faso, 2016a). A law establishing a Universal Health Insurance (*Assurance Maladie Universelle*, AMU) was adopted in September 2015 (Universal Health Coverage Partnership, 2015), as part of a broader strategy to work towards universal health coverage (Solidar, 2015). The legislation introduced major innovations in the social protection sector, including the establishment of a unique social service package and the introduction

of an equitable contributory financing system (Universal Health Coverage Partnership, 2015).

Health system governance and organisation

In 1997 the Burkinabé Ministry of Health took the decision to revise its national health system and to develop a 10-year national plan for the development of the health system, the *Plan National de Développement Sanitaire* (PNDS) (Ministère de la Santé du Burkina Faso). The plan was implemented between 2001 and 2010. The process involved the analysis of the healthcare situation in the country, the reformulation of the national healthcare strategy, and the elaboration of a national plan for the development of the health system.

In 2011, the Ministry of Health issued an updated PNDS covering the years 2011-2020. The new plan aims to build on the achievements of the first PNDS and address the remaining shortfalls in healthcare (Ministère de la Santé du Burkina Faso, 2011). Despite progress, however, difficulties remain in a number of areas, especially concerning measures to lower the financial barrier to affordable healthcare, the lack of funding and qualified personnel throughout the health system, as well as finding effective ways to transfer know-how and resources to the local levels (Ministère de la Santé du Burkina Faso, 2011).

Consequently, the new plan pursues two overarching goals: mitigating the remaining difficulties from the PNDS 2001-2010 and accelerating the path towards reaching the Millennium Development Goals (MDGs) (Ministère de la Santé du Burkina Faso, 2011). The PNDS 2011-2020 is organized around eight principal objectives:

- To develop leadership and governance within the health system;
- To improve the healthcare services offered;
- To develop the required human resources within the health system;
- To promote healthcare and the fight against communicable and non-communicable diseases;
- To develop healthcare-related infrastructure, equipment and products;

- To improve the management of health-related information system;
- To promote healthcare-related research;
- To increase healthcare funding and to improve financial access of the population to healthcare services.

The Burkinabé government is therefore seeking to enhance the healthcare standards and health of its population, creating a positive and proactive political and regulatory environment, where new technologies are potentially well perceived and embraced (Ministère de la Santé du Burkina Faso).

Public health and health service delivery

As outlined above, the health system in Burkina Faso and therefore also the Ministry of Health itself have undergone major reforms in the past decade and, given the recent establishment of the new government, the system is still in a slow process of change.

The Burkinabé health system is strongly influenced by the National Health Programme (*Politique Nationale de Santé*, PNS) and is divided into an administrative and a technical branch (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014).

The administrative branch is responsible for the operational planning and the implementation of the healthcare programmes throughout the country at national, intermediary, and peripheral level and is headed by the Minister of Health, Dr Smaila Ouédraogo (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014).

The central level of the administrative branch comprises the structures associated with the Cabinet of the Minister and the General Secretariat (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). The Central Direction is then hierarchically linked to the 13 Regional Directions (*Direction Régionale de la Santé*), which constitute the intermediate

level. The lowest level consists of 70 Healthcare Districts (*Districts Sanitaires*) which constitute the most granular operational entities of the national health system. These are spread throughout the national territory; only 63 are currently operational with the remaining 7 entities being still being expanded.

In 2014, a major revision of the internal organisation of the Ministry of Health and the national health system was initiated. The aim was to make the system more efficient (mainly in a cost-effective way) and to increase the functionality and efficacy of the institutions embedded in it.

In Burkina Faso, the Regional Directions and the Healthcare Districts are responsible for operational planning and implementation of healthcare programmes in geographical areas (Ministère de la Santé du Burkina Faso, 2016b). The Healthcare Districts also coordinate the activities of the *Centres de Santé et de Promotion Sociale* (CSPS) and of the *Centres Médical avec Antenne Chirurgicale* (CMA) (Ministère de la Santé du Burkina Faso, 2016b). Section 12.7 in the Appendix provides an overview of the organisation of the intermediary and peripheral levels and how these bodies are interconnected.

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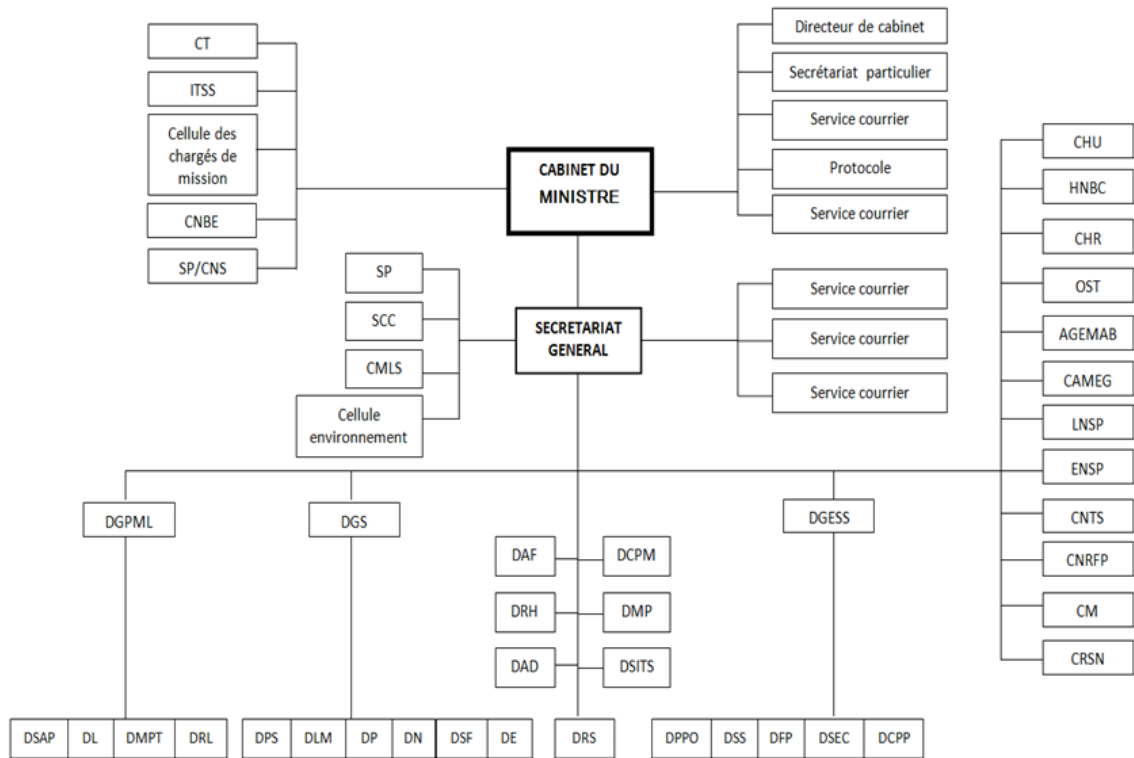


Figure 23: Organisational chart of Ministry of Health of Burkina Faso as of September 2016.

Abbreviations: CAMEG: CAMEG: Centrale d'achat de médicaments essentiels génériques et des consommables médicaux; CEDIM: centre de documentation de d'information sur le médicament; CNBE: Comité national de bioéthique; CHR: Centre hospitalier régional; CHN: Centre hospitalier national; CM: Centre Muraz; CNAOB: Centre national d'appareillage orthopédique du Burkina; CNLAT: Centre national de lutte antituberculeux; GNLC: Centre national de lutte contre la cécité; CNRFP: Centre national de recherche et de formation sur le paludisme; CNS: Conseil national de santé; CNTS: Centre national de transfusion sanguine; CMLS: Comité ministériel de lutte contre le SIDA; CRSN: Centre de recherche en santé de Nouna; CT: Conseiller technique; DAD: Direction des Archives et de la documentation; DAF: Direction de l'administration et des finances; DCPM: Direction de la communication et de la presse ministérielle; DCP: Direction de la coordination des projets et programmes; DES: Direction des établissements de santé; DFP: Direction de la formulation des politiques; DGPML: Direction générale de la pharmacie, du médicament et des Laboratoires; DGESS: Direction générale des études et des statistiques sectorielles; DGS: Direction générale de la santé; DL: Direction des laboratoires; DLM: Direction de la lutte contre la maladie; DMP: Direction des marchés publics; DMPT: Direction de la promotion de la médecine et de la pharmacopée traditionnelles; DN: Direction de la nutrition; DPPO: Direction de la prospective et de la planification opérationnelle; DPS: Direction de la promotion de la santé; DPV: Direction de la prévention par les vaccinations; DRH: Direction des ressources humaines; DRLP: Direction de la réglementation et des licences Pharmaceutiques; DRS: Direction régionale de la santé; DS: District sanitaire; DSAP: Direction de la sécurisation des approvisionnements pharmaceutiques; DSEC: Direction du suivi, de l'évaluation et de la capitalisation; DSF: Direction de la santé de la famille; DSITS: Direction des services informatiques et de la télésanté; DSS: Direction des statistiques sectorielles; ENSP: Ecole nationale de santé publique; ITSS: Inspection technique des services de santé; LNSP: Laboratoire national de santé publique; MCD: Médecin-chef de district; OST: Office de santé des travailleurs; SDA: Service de la documentation et des archives; SCC: Service central du courrier; SP: Secrétariat particulier ou permanent; SP/CNS: Secrétariat permanent du conseil national de santé.

Based on: (Ministère de la Santé du Burkina Faso, 2016b).

The technical branch comprises the health institutions that directly deliver services, treatments and medicines to the Burkinabé population (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). These public structures are subdivided in three levels of care: primary, secondary, and tertiary.

For patients, the first points of contact are the Primary Health Centres or the Primary Care Practices (*Centre de santé et de promotion sociale*, CSPS), which are designed to be set up in the immediate proximity of the patient (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). There are approximately 1,600 CSPS spread across the country. The bulk of health care is being delivered at this primary level. Nevertheless, over 23% of the population (country average ranging from 0.6% to 47.8% in the various districts) lives over 10 km away from those facilities, and this geographical inaccessibility makes them hard to reach (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). These primary facilities are exclusively run by midwives and nurses; no doctors work in CSPS. Independently of the type of disease or illness and the gravity of it, patients have to visit a CSPS as a first step before they can be referred to the next level of care.

Although they are still regarded as primary care facilities, the next level of care comprises Medical Centres which can be equipped either with or without a surgical unit (*Centres Médicaux*, CM / *Centres Médicaux avec Antenne Chirurgicale* - CMA) (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). Currently, there are only 45 active Medical Centres in Burkina Faso (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014), fewer than one per district. In addition, these are unevenly distributed across the country, given that the Plateau Central has a disproportionate number of facilities. In these facilities, doctors are usually able to deal with general medical issues and are often used for complicated deliveries (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014).

Secondary care is provided by the Regional Health Centres (*Centres Hospitaliers Régional*, CHR) which serve as a reference for the CMAs and where more critical and/or complicated cases are treated (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). The tertiary level comprises the 3 University Hospitals (*Centres Hospitaliers Universitaires*, CHU) located in the two main cities of the country, Ouagadougou and Bobo-Dioulasso (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014).

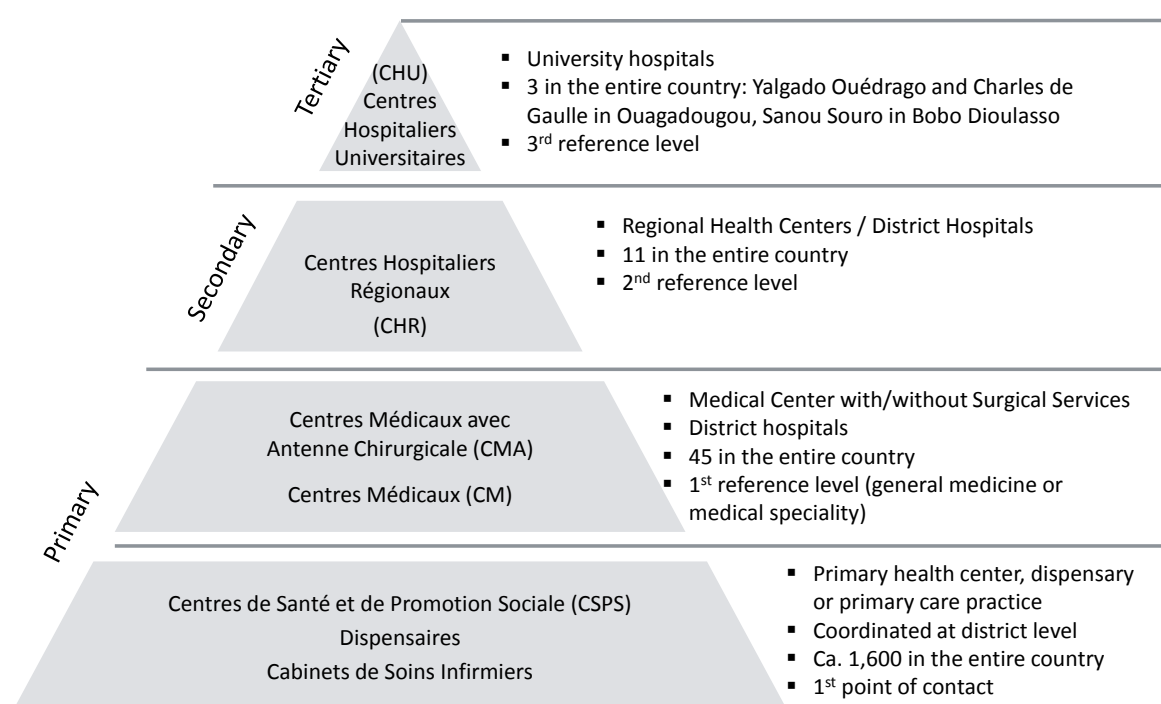


Figure 24: Distribution and organisation of medical structures in Burkina Faso.

At all levels, the individual centre committees are directly responsible for the governance of these structures. The centre committees work together with the Regional Directions and the Directors of the Healthcare Districts but have autonomous budgets.

Prices for the provision of any service within these structures and for transportation of patients from one structure to another are fixed by the government and are independent from the income of the individual receiving the treatment.

Furthermore, the referral system from one facility to another, as it is currently organised, prolongs the time between the first visit and the actual cure, thus increasing the prices that patients have to pay.

A major problem of the current system is that the hospitals receive very little funding from the government and need to complement their income through direct payments from patients. Since the cost of the services is very high compared to the average disposable income, only few people can afford payment for the treatments. As a consequence, a high percentage of the low-income populations do not go to the hospital, but to traditional healers for their treatment. Consequently, institutions in some regions, especially the CHRs, are encountering serious financial difficulties due to a lack of funding.

In addition to the healthcare structures of the Ministry of Health, other public structures are involved in care of the Burkinabé population (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). These are the Armed Health Services (*Services de Santé des Armées*, SSA) and the Health Services of the National Social Security Fund (*Services de Santé de la Caisse nationale de Sécurité Sociale*, CNSS). These institutions are governed by the Ministry of Defence and the Ministry of Social Security respectively.

Besides the public structures, there are also 384 private health facilities in the country (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). These are mainly distributed within or in the outskirts of the two major cities, Ouagadougou and Bobo-Dioulasso and target the wealthier population.

In recent years, the Ministry of Health has started to officially recognise the importance of the traditional medicine and has launched a technical direction to improve coordination of the sub-sector (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014), the *Direction de la Promotion de la Médecine et de la Pharmacopée Traditionnelles* (DMPT).

Malaria Eradication Programme

Despite the many efforts undertaken in recent years to reduce the burden of malaria, in Burkina Faso the vector-borne disease still accounts for ca. 47% of the deaths and for ca. 85% of deaths of children under 5 years (Combary, 2011), making it the primary cause of death in the country.

The *Programme National de Lutte Contre le Paludisme* (PNLP) (the National Programme for the Fight against Malaria) was set up by the Government to tackle malaria. The government body in charge is the *Direction de la Lutte Contre le Paludisme*. The new strategic plan (2011 - 2015) of the PNLN aims to reduce the number of deaths caused by malaria to 1 in every 100,000 inhabitants by the end of 2015 (Combary, 2011). This implies a reduction of morbidity by 75% since 2000 (Combary, 2011). The main measures to achieve this goal are:

- Improve the management of the malaria cases;
- Enforce malaria prevention, especially for pregnant women and children under 5 years of age;
- Reinforce the fight against the vectors of malaria;
- Improve the management of procurement of antimalarial medicines;
- Reinforce the advocacy, information, education, communication, and social mobilisation around the issue of malaria;
- Improve the management of the programme itself.

The intensified efforts by the national authorities in the combat against malaria are a strong indication that the eradication of vector-borne diseases is at the top of their national healthcare agenda. This potentially enhances the readiness of the Burkina Faso health system to adopt new innovative technologies.

Public understanding of malaria

A 2014 Malaria Indicator Survey (MIS), performed by the Demographic and Health Surveys (DHS) team of USAID in collaboration with the Ministry of Health, showed that the general knowledge of Burkinabé people, especially women, on malaria, its causes and prevention methods, has improved over the past years, but remains inadequate (Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014).

Most women recognise and identify fever (80%), lack of appetite and vomiting (56%), as well as headaches (30%) as symptoms of malaria. Other symptoms are less commonly known and there are strong regional differences and discrepancies in knowledge of the disease that are related to the enrolment rate. In fact, 67% of women can be considered as having good knowledge of malaria – they know that fever is a sign of malaria, that mosquitoes are a vector and that sleeping under an insecticide treated net (ITN) is an effective prevention measure. Local radio is reported as the main source of regular messages related to malaria (41%), followed by local health workers who deliver malaria awareness messages to villages (29%) (Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014).

Nevertheless, despite all the efforts and public campaigns undertaken to improve public understanding of vector-borne diseases and malaria in particular, there are still a large number of misconceptions deeply rooted in the Burkinabé culture. This is mostly due to people's perceptions of malaria as a problem. Especially in rural areas, the excessive consumption of different sorts of fatty or sweet foods (e.g. mangoes, milk, sweets, old oil), the direct exposure to the sun, lack of sleep, exhaustion due to excessive labour, and contact with rainfall are all believed to transmit malaria, impeding prevention methods (Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014).

A major problem is that the majority of malaria symptoms, besides fever, are often attributed to other illnesses, usually thought to be caused by evil spirits and only rarely by natural causes. This holds especially true when a high fever leads to hallucinations or convulsions. As a result, malaria treatment is often not sought or only sought after major delays, drastically reducing the chances of full recovery.

Moreover, malaria itself is perceived as a common, curable disease and is not perceived as a major problem by the population, let alone as the major cause of death and hospitalisation in the country.

All of these misconceptions have therefore resulted in a lack of recognition of the disease and hence of its treatment, and pose barriers to the adoption of malaria prevention and eradication methods.

7.2.3 Technological development in Burkina Faso

Burkina Faso's experience with the development of its information and communications technology (ICT) infrastructure over the past 15 years illustrates the difficulties the country has had in introducing technology-based innovations. There has been a slow and difficult, but nevertheless coordinated, shift towards digital technology adoption and implementation, demonstrated in the relatively slow pace of development in telecommunications. The poor state of the Burkinabé fixed-line telephone network, coupled with the virtual non-existence of governmental policies and regulatory frameworks to encourage the technological development of the telecommunication sector, has led to a steady decline of the fixed-line subscribers (less than 1% of the population in 2015). Existing users have mainly switched to the limited services available from mobile networks operators (BuddeComm, 2016, Central Intelligence Agency, 2016). While the lack of government policy has impeded the growth of 3G and LTE mobile services (BuddeComm, 2016), the mobile sector has nevertheless steadily grown and has a current market penetration of approximately 76% (albeit below the African average) (Internet World Stats, 2016).

The provision of internet services was poor until the mobile operators began to enter the market by offering mobile data services. This generated an exponential rise in internet penetration, from approximately 10,000 users in December 2000 to roughly 1.89 million in June 2016, although this 9.7% population penetration is still significantly below African averages of 28.7% (Internet World Stats, 2016). This is

due to the fact that services remain expensive, despite a series price cuts introduced since 2011, and the network is limited with many areas without network coverage.

In April 2016, the new Burkinabé President, Roch Kaboré, launched a new eBurkina project jointly with the World Bank in order to make information and communication technologies more accessible and cost-efficient for everyone. The project also aims to improve government services and infrastructure by digitally connecting public agencies, schools and health facilities, registering all new-borns and generating a unique digital ID for each citizen, as well as improving education, health and agriculture.

Experience with GM technologies – the case of Bt cotton

Despite the socio-economic difficulties and the low level of digital technological development faced by Burkina Faso, the country has managed to establish a leadership role on biotechnology and biosafety matters over the years – both in the West African region as well as in the total African continent (International Service for the Acquisition of Agri-biotech Applications (ISAAA), 2016).

Burkina Faso signed the Cartagena Protocol in May 2000 and ratified it in August 2003 (African Biosecurity Network of Expertise (ABNE), 2016a). This allowed the US seed company Monsanto to import GMOs into the country for R&D purposes and for confined field trials. In 2016, Burkina Faso was one of the only 14 countries on the African continent that had confined field trials for GMOs, as well as appropriate biosafety laws in place for the safe deployment of GMOs on the ground (African Biosecurity Network of Expertise (ABNE), 2016a). Furthermore, Burkina Faso is, together with Sudan and South Africa, one of only 3 African countries producing commercialised GM crops (African Biosecurity Network of Expertise (ABNE), 2016a). The example of the adoption and diffusion of Bt cotton in Burkina Faso provides a useful illustration of the introduction of this type of technological innovation, in particular the impact of the wider socio-cultural, economic and governance factors in shaping its pattern of adoption and diffusion.

The country started commercially growing Bt cotton (Bollgard II) in 2008 and there were seven consecutive years of cultivation until late 2015 (James, 2011, African Biosecurity Network of Expertise (ABNE), 2016a). Until now, it is the only GM organism present in the country being cultivated for commercial use (James, 2011). The technology was widely adopted by farmers for two reasons. Firstly, Bt cotton crops, unlike normal cotton, do not need to be treated with specific pesticides, which have highly detrimental effects on the health of farmers. This benefit of improved health, offering a quick solution to a problem close to the people's perception and needs, was seen as a key factor for overcoming the fears around GM products and creating swift adoption. Secondly, despite the higher costs, Bt cotton led to higher yields in the first years of use. In 2015, throughout the country, approximately 110,760 farmers were growing 350,000 hectares of Bt cotton, equivalent to 50% of the total cotton planting area in the country (International Service for the Acquisition of Agri-biotech Applications (ISAAA), 2016). However, there was a 23.8% reduction compared to the peak levels in 2014, mainly due to concerns, fostered by international NGOs, about the efficiency of the technology, risks and sustainable profit levels for the thousands of smallholder producers who face enduring poverty and low agricultural productivity (Collectif Citoyen pour l'Agro-Ecologie, 2016). This led to several anti-GM campaigns with anti-GMO and anti-Monsanto rallies throughout the country and especially in the two major cities, Ouagadougou and Bobo-Dioulasso (Agence France-Presse, 2016, Collectif Citoyen pour l'Agro-Ecologie, 2016, Bassole, 2016). This action culminated in the suspension of Bt cotton cultivation by the Burkinabé Union of Cotton Producers (*Union Nationale des Producteurs de Coton du Burkina*, UNPCB) across the country. The government has commissioned a study to determine whether the claims are correct that the fibre length of GM cotton is decreasing over time, thus reducing the annual cotton yields of farmers (African Biosecurity Network of Expertise (ABNE), 2016a, Mokhema and Gumede, 2016). Furthermore, the Inter-professional Cotton Association of Burkina (AICB) has claimed CFA 48.3 billion (USD 83.9 million) from Monsanto as compensation for their crop yield losses (Bonkounou, 2016).

Chapter 7

At present, the biosafety authorities are working together with the local scientific community to draft the country's official position on the issue (African Bioesefety Network of Expertise (ABNE), 2016a). At the same time, civil society groups - in contrast to anti-GMO NGOs - are forming in order to support GM agriculture products and advocate for farmers' rights to benefit from improved seeds of their choice (African Bioesefety Network of Expertise (ABNE), 2016a). Furthermore, Burkina Faso remains a strong advocate of R&D in GMO and the country currently holds confined field trials on stacked insect resistant and herbicide tolerant cotton, on Bt cowpea, as well as on insect resistant maize (Bt maize) and a stacked insect resistant and herbicide resistant maize (Bt X RRF) (African Bioesefety Network of Expertise (ABNE), 2016a). In 2016 Burkina Faso was the first country to import a self-limiting strain of transgenic *Anopheles gambiae* mosquitoes, which could have a major impact in the fight against malaria and to allow confined lab testing at IRSS (African Bioesefety Network of Expertise (ABNE), 2016a).

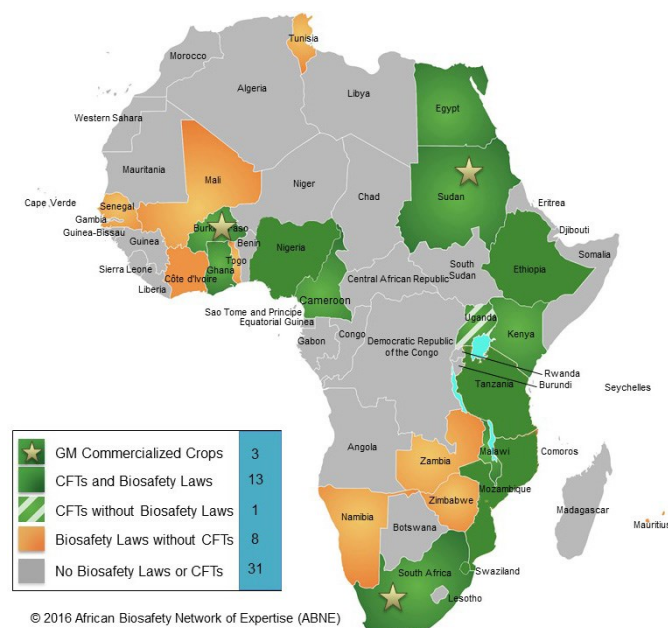


Figure 25: Map of the current stage of biosafety laws, confined field trials and commercialised GM crops in Africa.

Based on: African Bioesefety Network of Expertise (ABNE) (2016b).

7.2.4 Governance of GMOs in Burkina Faso

National Biosafety Committee and regulatory laws

In Burkina Faso, biosafety and the safe regulation of all GMOs are the responsibility of the National Biosafety Committee, which is composed of the National Biosafety Agency (*Agence Nationale de Biosécurité*, ANB) and two advisory bodies: the National Scientific Committee for Biosafety (*Comité Scientifique National de Biosécurité*, CSNB) and the National Observatory for Biosafety (*Observatoire National de Biosécurité*, ONB) (Dayamba, 2013).

The main national regulatory authority is the National Biosafety Agency (ANB), which is in charge of a series of key responsibilities. Among those tasks are developing application forms, ensuring that risk assessments are completed, granting permissions for the different uses of GMO, checking the conformity of laboratories and greenhouses, as well as inspecting equipment and infrastructures, ensuring public awareness in biotechnology and biosafety, and ensuring public participation to decision making (Dayamba, 2013). In order to achieve these goals, the ANB closely collaborates with the National Scientific Committee for Biosafety (CSNB) and the National Observatory for biosafety (ONB) (Dayamba, 2013).

The CSNB is in charge of the development of scientifically sound, case-by-case risk assessments for each application. The committee is composed of 12 members and can recruit external experts on an as-needed basis (Dayamba, 2013).

The ONB is the body in charge of monitoring the progress in the country with respect to biotech and biosafety issues (Dayamba, 2013). Hence, its major tasks are GMO surveillance and control as well as the organisation and execution of public awareness campaigns (Dayamba, 2013). The body is formed by 33 members of the public administration and civil society (Dayamba, 2013).

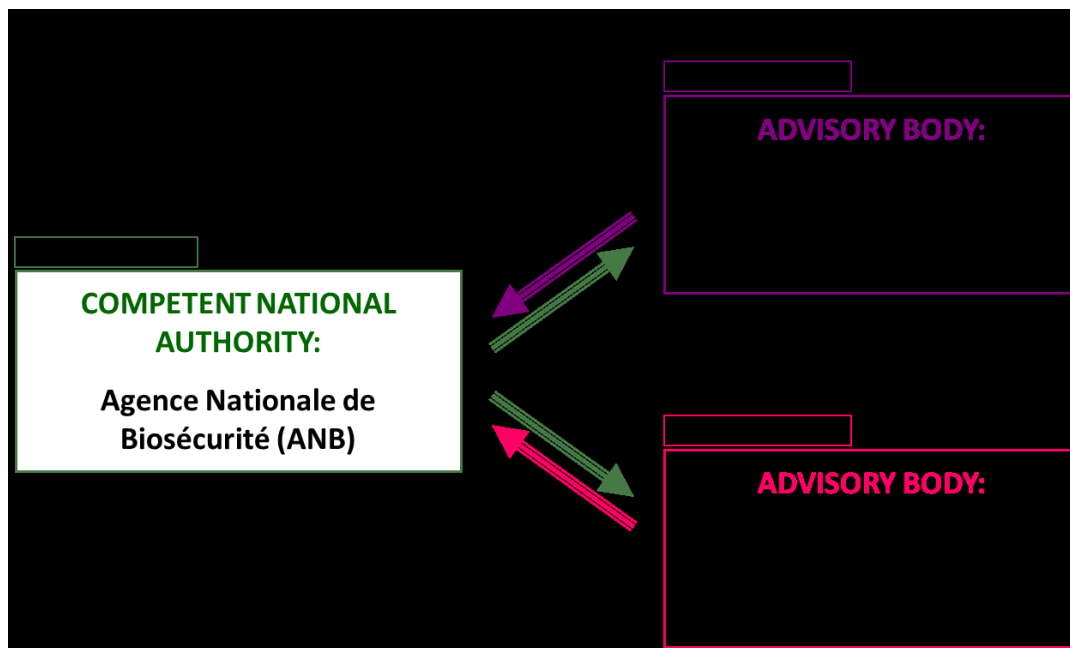


Figure 26: Overview of the authorities and bodies forming the Burkinabé National Biosafety Committee.

Based on: Dayamba (2013)

The work of the Burkinabé National Biosafety Committee is governed by three major, nationally-recognised, regulatory documents: the international Cartagena Protocol, the Burkinabé National Rules pertaining to safety in biotechnology, and the Burkinabé Law n°005-2006/AN (Dayamba, 2013).

The Cartagena Protocol on Biosafety to the Convention on Biological Diversity is an international treaty governing the movements (including safe handling, transport and use) of living modified organisms (LMOs) resulting from modern biotechnology from one country to another (Convention on Biological Diversity, 2016). This treaty takes into consideration the fact that those organisms may have adverse effects on biological diversity, taking also into account risks to human health (Convention on Biological Diversity, 2016).

The National Rules pertaining to safety in biotechnology are a set of rules regarding different aspects of biosafety. These were developed by the Burkinabé Government in 2004 and used for guidance before the adoption of the biosafety law, which was the outcome of a dialogue between stakeholders in biotechnology and biosafety (Dayamba, 2013).

The Law n°005-2006/AN of March 17, 2006 regulates safety regimes pertaining to biotechnology matters in Burkina Faso. It determines the conditions for use of GMOs and other biotechnology products (excluding pharmaceuticals) in the country (Government of Burkina Faso, 2006). It also regulates GMO development, experimentation production, dissemination, storage, destruction, elimination, and transit and trans-boundary movements (Government of Burkina Faso, 2006, Dayamba, 2013).

The regulatory process

Burkina Faso now has a formalised process for reviewing and regulating GM technologies being introduced into the country, either commercially or through scientific research. The process is initiated when the applicant submits its application dossier – providing information on the safety of the product – to the National Biosafety Agency (ANB) (Dayamba, 2013, Interviewee 42 US-SL-IU-ADA-HE, 2016) (Interviewee 41 UK-LN-IU-LLA-BE, 2016). The ANB then performs a preliminary evaluation of admissibility to ensure that all the necessary information has been provided, but it is not an evaluation of the content. At the same time, the application is sent to the National Scientific Biosafety Committee (CSNB)(Dayamba, 2013), which conducts the actual risk assessment, reviews the application from a scientific perspective and verifies the assertion of safety. This is done by verifying that there are no plausible routes to potential harm. The CSNB can recruit external national or international experts to support them in the assessment. It then makes a recommendation based on the risk assessment and the evaluation of the technology to the ANB. The National Biosafety Agency then sends out the results of the risk assessment to the National Observatory for Biosafety (ONB). This is a consultative, monitoring agency which observes any activities in the country with respect to biotech and biosafety issues and reporting them back to the ANB.

In case of an open field release, the ANB also has to make the same information available to the general public and to host a public inquiry. This engagement process varies, depending on the potential impact of the activity on the population and

environment. Once the ANB has gathered all required information, it makes a final recommendation based on the risk assessment, the evaluation of the ONB and comments raised by public inquiries to the Minister in charge of biosafety. The Minister then publishes a Ministerial Order with the final decision, which can either be refusal or permission subjected to specific conditions. The decision is communicated to the public, as well as transmitted to the Cartagena Protocol Biosafety Clearing House and to the applicant (Dayamba, 2013, Interviewee 42 US-SL-IU-ADA-HE, 2016).

The statutory timeframe for assessment is 150 working days, from the acknowledgment of receipt to the transmission of the Ministerial Order (Interviewee 41 UK-LN-IU-LLA-BE, 2016, Interviewee 42 US-SL-IU-ADA-HE, 2016). Nevertheless, if any of the committees require additional information from the applicant, they can “stop the clock” until the information is provided.

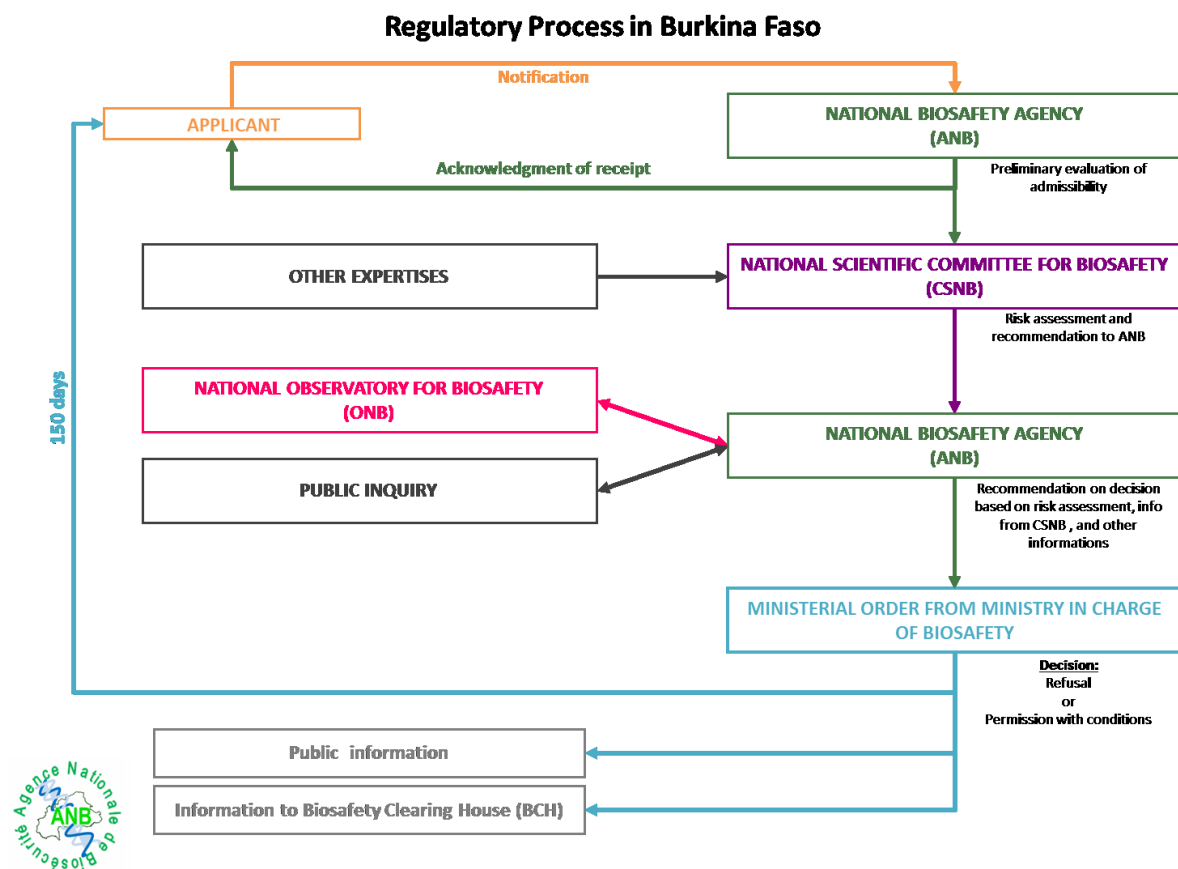


Figure 27: Regulatory Process in Burkina Faso for GMOs.

Based on: Dayamba (2013)

7.3 Discussion

As outlined in Section 7.2.1, the Burkinabé population remains young due to a constantly high reproduction rate, currently measured at 5.7 live births per women (UN Data, 2016). Even though the majority of the population remains rural, an increasingly rapid urbanisation trend was observed in recent years (Central Intelligence Agency, 2016). The combination of these factors (young population and urbanisation) will likely have implications on the adoption of malaria intervention as well as on the adoption of complex innovations (i.e. GM technologies). The statistical correlations between demographic factors and the adoption of conventional malaria interventions (i.e. usage of bednets) will be established in Chapter 8.

As a result of the new policies adopted within Burkina Faso's health system (see Section 7.2.1), health measures are slowly improving with observed life expectancy increasing by approximately 10 year between 1990 and 2015 for both men and women (Institute for Health Metrics and Evaluation, 2016a). Nevertheless, communicable diseases still constitute a significant health risk, with malaria remaining the primary cause of death in 2015. This is also reflected in the causes of disability adjusted life years (DALYs), where malaria is ranked as the biggest contributor (Institute for Health Metrics and Evaluation, 2016a, Institute for Health Metrics and Evaluation, 2016c). As a result of this, significant resources have been deployed in malaria elimination programmes (see. 7.2.2) funded by both national and international organisations.

The strong communicable diseases' prevalence – and malaria in particular – is further aggravated by Burkina Faso's unstable economic situation, driven by a lack of natural resources and difficult climatic conditions (World Bank, 2016a, Encyclopædia Britannica, 2016). This situation is made worse by poor education levels throughout the Burkinabé population with a literacy rate for young people of only 36% in 2015 (Central Intelligence Agency, 2016). This, in turn, leads to a high unemployment rate and more than 40% of the population living below the poverty line (World Bank Data, 2016b). The intricacies and interdependencies between those factors are modelled and in Chapter 9 following a systems thinking approach.

This vicious circle of lack of education and the ensuing unemployment also has implications for the fight against malaria. Low literacy levels prevent large part of the population from informing themselves about malaria, whereas high poverty will likely shift priorities towards the economic survival rather than combatting malaria.

After a prolonged period of instability and unrest, the political situation in Burkina Faso has recently stabilized and a parliamentary republic has been established (Encyclopædia Britannica, 2016). This process has also resulted in positive externalities in the healthcare sector as a number of structural reforms were triggered.

Besides the economic and political conditions, also the socio-cultural context plays a crucial role in the combat against malaria. Burkina Faso's society is composed of a multitude of ethnicities, languages and religious affiliations, resulting in a melting pot of over 60 ethnic groups (Our Africa, 2015). Owing to their heterogeneous background, history and traditions are mainly passed on via musical storytelling from generation to generation. Regardless of being a rather tolerant people, the Burkinabé society is male-dominated which is also reflected in the composition of the elected political bodies. On a community level, informal community leaders, i.e. the *chef coutumier* or 'leader of tradition', play an important role in addition to the formal leaders, i.e. the village chiefs and CVDs. In giving guidance on spiritual issues and local traditions they are also key stakeholders in all malaria-related interventions on community levels. Due to their influence in their respective communities their attitude towards health interventions determines the adoption success in those communities to a great extent.

Having been detrimentally impacted by the prevailing instabilities in 2014-15, the Burkinabé health system is now moving towards improving coverage, following the guidelines laid out in the new PNDS (Ministère de la Santé du Burkina Faso, 2011). The public health service delivery is facilitated by a reasonably well structured three-tier system (Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014). However, access to the health system remains a challenge, driven by geographical, financial and cultural hurdles. Besides academic medicine, also traditional healing represents an important part of the

system; this has recently resulted in the foundation of the Direction de la *Promotion de la Médecine et de la Pharmacopée Traditionnelles* (DMPT).

A significant portion of the government's healthcare efforts are directed at the elimination of malaria with the *Programme National de Lutte Contre le Paludisme* (PNLP) as a focal point. Despite these efforts, an imperfect understanding of the disease still prevails in the Burkinabé society (Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014). This lack of understanding presents a big challenge for all malaria programmes, both for conventional interventions and for the introduction of more complex technologies.

Despite the challenges in improving public awareness for malaria, the introduction of GM technologies could be facilitated from a regulatory perspective. As a result of the coherent and seemingly robust governance structure put in place (best-in-class in Africa), transparent processes for sanctioning and monitoring GMOs can be followed.

8 Econometric analysis of the determinants leading to the adoption of malaria elimination interventions in Burkina Faso

This chapter discusses the variables relating to geographic, socio-demographic, household, economic, and healthcare-related factors influencing the adoption of interventions targeting malaria prevention and elimination in Burkina Faso.

Chapter 2 elucidates the research literature on the adoption and diffusion of health technology innovations, both in developed and developing health system contexts. The author considered the specific features of the healthcare sector that are challenging for the introduction of new technologies. The challenges in implementing and sustaining technological innovations in health systems in low- to middle-income countries were also outlined, notably the development of inappropriate technology, presence of social, economic, cultural and technical barriers, and the lack of attention to the processes for scaling up innovations beyond pilot stages.

In Chapter 5, the author turned to the adoption and diffusion of interventions for malaria eradication. Through a systematic review of the research literature, the key interventions and factors which have been shown to influence their adoption and use in mainstream healthcare practice were explored.

Chapter 8 draws together these findings, to explore the experience of adopting and diffusing malaria elimination tools in Burkina Faso, notably bednets, intermittent preventive therapy for malaria prevention during pregnancy (IPTp), and antimalarial drugs. The rationale for choosing these comparators was mainly driven by the types of malaria elimination interventions that have been deployed in Burkina Faso over the past 15 years, as well as by data availability.

A key characteristic of these technologies is that they are ‘private goods’, i.e. decisions about adoption are made by *individuals* on the basis of a range of factors like cost, availability, and perceived efficacy. Even though this PhD thesis is mainly concerned with ‘public goods’, i.e. genetically modified mosquitoes, understanding

the socioeconomic and demographic factors which influence the adoption of these types of technology was nevertheless important for two reasons.

Firstly, it allowed to contrast technologies targeted at malaria elimination that are essentially a private good with those that are a public good, such as GM mosquitoes

Secondly, although the types of technology are different, understanding the socioeconomic and demographic factors which help to determine the adoption of previous malaria prevention innovations in Burkina Faso provided some valuable insight into the overall prevailing attitudes towards innovation adoption, which were then triangulated with findings on genetically modified mosquitoes in the case study analysis in Chapter 9.

In order to perform this analysis the author was granted access to the socio-demographic and population's health surveys of Burkina Faso from 'The Demographic and Health Surveys (DHS) Program'. The DHS programme is funded by the U.S. Agency for International Development (USAID) and has provided technical assistance to more than 300 surveys in over 90 countries since 1984, thus advancing global understanding of health and population trends in developing countries (The DHS Program, 2016).

The surveys used for this PhD study contain data collected by the Burkinabé National Institute of Statistics and Demography (Institut National de la Statistique et de la Démographie et al., 2004, Institut National de la Statistique et de la Démographie (INSD) et al., 2012, Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014) through personal interviews with survey respondents, and include nationally representative data on fertility, family planning, maternal and child health, gender, HIV/AIDS, malaria, and nutrition (The DHS Program, 2016). The Burkina Faso data covers the years 2003, 2010, and 2014. The 2010 DHS survey is the most comprehensive of the studies performed on the ground (Institut National de la Statistique et de la Démographie (INSD) et al., 2012) and was used as the baseline dataset in this PhD study. The 2003 dataset contains most of key performance indicators of the 2010 survey but only a reduced set of data for all impact evaluation measures (Institut National de la Statistique et de la Démographie et al., 2004). The 2014 dataset is a Malaria Indicator Survey (MIS) and

hence contains all malaria indicators, but only a subset of the demographic indicators (Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014). For this reason, it was not possible to perform all regressions for 2003 and 2014, and the analysis needed to be tailored to the existing datasets. The specific country survey questionnaires were reviewed in detail for each year in order to determine the possible research questions and the potential unit of analysis (e.g. household, population, women, or children) for each one.

The data enabled investigation of the following questions, designed to explore the specific expression in the Burkina Faso context of the factors identified in the prior literature review on adoption of innovation within health systems (see Chapter 2), as well as in the systematic literature review on the adoption of malaria interventions tools:

Which are the statistically relevant geographic, socio-demographic, household, economic, and healthcare-related factors that influence the:

- **Ownership of bednets at household level for 2003 and 2010;**
- **Use of bednets at population's level in 2003, 2010, and 2014;**
- **Use of bednets at women's level in 2003 and 2010;**
- **Use of bednets at children's level in 2003 and 2010;**
- **Uptake of Intermittent Preventive Therapy for malaria prevention during pregnancy (IPTp) at women's level in 2010 and 2014;**
- **Uptake of multiple doses of IPTp at women's level in 2010;**
- **Uptake of SP Fansidar (WHO and country recommended medication) compared to other medicines for IPTp at women's level in 2010 and 2014;**
- **Use of antimalarial drugs (type) during fever at children's level in 2010 and 2014;**
- **Prompt use (timing) of antimalarial drugs during fever at children's level in 2010 and 2014.**

8.1 Methodology

8.1.1 The Burkina Faso DHS and MIS surveys – data source and participants

The datasets are from the Burkina Faso standard Demographic and Health Survey (DHS) of 2010 (DHS-VI) and 2003 (DHS-IV), as well as with data from the Burkina Faso Malaria Indicator Survey (MIS) of 2014 (DHS-VII). The Burkina Faso standard DHS of 1998/9 (DHS-III) and of 1993 (DHS-II) were discarded because they do not contain enough malaria data to perform the study.

All three relevant surveys, the DHS 2003, DHS 2010, and MIS 2014, are nationally representative surveys with a cross sectional design with a random two-staged stratified sampling (Institut National de la Statistique et de la Démographie et al., 2004, Institut National de la Statistique et de la Démographie (INSD) et al., 2012, Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014) and the following effective sample sizes:

- DHS 2003: 9,097 households, 12,477 women aged 15-49, 3,605 men aged 15-59, and 10,645 children under 5 years (Institut National de la Statistique et de la Démographie et al., 2004);
- DHS 2010: 14,924 households, 19,352 women aged 15-49, 8,127 men aged 15-59, and 15,044 children under 5 years (Institut National de la Statistique et de la Démographie (INSD) et al., 2012);
- MIS 2014: 6,552 households, 7,483 women aged 15-49, and 7,319 children under 5 years (Institut National de la Statistique et de la Démographie Ouagadougou et al., 2014).

For the two DHS and the MIS surveys the household (HR), household member (PR), women (IR), and children (KR) recodes which contained the necessary variables for the analysis were used. In each case the recodes were appropriately merged in order to have a complete dataset for each year. These were then cleaned and, where necessary, recoded in order to get a coherent dataset for each year. Missing values and other exceptions like special values were also accounted for.

Sample weights were applied to all analysis groups in order to make sample data representative of the entire population.

The smallest sample size amongst our different specification always allows estimating the relative effect with statistical certainty of at least 0.001.

8.1.2 Study variables

The main *outcome variables* used for the analysis are listed in Table 3 and were subdivided in the following 3 categories: binary discrete variables, ordered discrete variables and ordered count variables.

Outcome variable	Variable type	Variable description
Insecticide treated net (ITN) ownership	binary discrete	'o' HH does not own any bednet; '1' HH owns bednet
ITN use	binary discrete	'o' no use of bednet; '1' slept the night before under a bednet
Intermittent Preventive Therapy in pregnancy (IPTp) uptake	binary discrete	'o' no doses of SP/Fansidar taken; '1' at least one dose of SP/Fansidar taken
Multiple doses of IPTp uptake	ordered discrete (with threshold)	'o' no dose; '1' 1 dose; '2' 2 doses; '3' 3 or more doses of SP/Fansidar taken
SP/Fansidar uptake	binary discrete	'o' SP/Fansidar was taken for IPTp; '1' other antimalarial drugs taken for IPTp
Antimalarial drugs use against fever	binary discrete	'o' no use or painkiller taken; '1' antimalarial drugs taken
Prompt antimalarial drugs use	ordered count	Number of days elapsed before starting the antimalarial treatment

Table 3: Outcome variables used for the determination of geographic, demographic, and socio-economic factors influencing the uptake of various malaria elimination technologies in Burkina Faso.

The ITN ownership outcome variable was created from the variable v459 'Have mosquito bed net for sleeping (from HR)'. All the missing and not applicable

answers were dropped leaving a binary variable with 'no' (no bednet owned) and 'yes' (bednet owned).

The ITN use outcome variable at population level was generated from variable hml12 'Type of Mosquito Bed Net(s) person slept under (from HR)'. A binary variable called 'useofbednet_HR' was generated to limit the variable to 'no' (no bednet used) and 'yes' (for hml12 > 0). All the missing and not applicable answers were dropped.

At the same time, variable v461 'Respondent slept under mosquito bed net (from IR)' was used as the ITN use outcome variable at women level after having dropped all missing and not applicable answers.

The ITN use outcome variable at children level was constructed from v460 'Children under 5 slept under mosquito bed net (from IR)'. A binary variable called 'useofbednet_KR' was with only two levels: 'no' (no bednet used) and 'yes' (for v460 > 0).

The IPTp uptake outcome variable was created from variable m49a 'During pregnancy took: SP/fansidar for malaria (from IR)' for 2010 and from variable s307a 'During pregnancy took: SP/fansidar for malaria (from IR)' for 2014. In both cases the variable was limited to either those who received IPTp (yes) or who did not receive IPTp during pregnancy (no), and all missing and not applicable answers were dropped. IPTp uptake was limited to SP/Fansidar as it is the only IPTp drug recommended for Burkina Faso by the WHO and the Burkinabé Ministry of Health.

The multiple doses of IPTp uptake variable is constructed from levels of variable ml1_1 'Number of times took Fansidar during pregnancy (from IR)'. The variable takes positive integer values relatively to the number of SP/Fansidar doses assumed. All missing and not applicable answers were dropped.

An assessment of the women taking SP/Fansidar for IPTp versus those taking another medication for IPTp was also made. In this case a variable called 'fansidaruse' was generated from the group of variables m49x_1 to m49x_6 'During pregnancy took: other drug for malaria (from IR)'. This variable constructed to take the value 0 when any dose of SP/Fansidar is assumed, and value 1 when any other antimalarial drug is taken up. All missing and not applicable answers were dropped.

When assessing the use of antimalarial drugs against fever in children, the group of variables ml13x_1 to ml13x_6 'Other taken for fever/cough (from KR)' is taken into consideration to weigh the correct use of those medications. In order to do this a binary variable called 'useoftreat' was constructed to take the value 0 when a random drug was given to the child, and to take the value equal to 1 when an antimalarial drug was taken. All missing and not applicable answers were dropped.

In order to establish the prompt use of antimalarial drugs, a count variable called 'timing' was created. This variable measures the number of days before a child received the antimalarial treatment. The variable is constructed from the mutual exclusive combination of the following variables: ml15a 'Timing of start of Fansidar', ml16a 'Timing of start of Chloroquine', ml17a Timing of start of Amodiaquine', ml18a 'Timing of start of Quinine', ml20a 'Timing of start of Artemisinin', and ml21a 'Timing of start of CS antimalarial use'.

The following *independent variables* were assessed for associations with the use and uptake of malaria elimination technologies. These included a range of geographic, socio-demographic, household, economic, and variables relating to population use of healthcare. These were classified and explained as follows.

Geographic characteristics:

Independent Variable	Variable description	Name of variable in dataset
Region of residence	Boucle de Mouhoun (base), Cascades, Centre, Centre-Est, Centre-Nord, Centre-Ouest, Centre-Sud, Est, Hauts Basins, Nord, Plateau Central, Sahel, and Sud-Ouest. NB: all regions are considered to have the same malaria transmission characteristics hence no malaria risk areas were considered	hvo24
Area of residence	Urban, and rural (base)	hvo25

Table 4: Independent variables used for the determination of geographic factors

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Socio-demographic and cultural characteristics:

Independent Variable	Variable description	Name of variable in dataset
Religion	Catholic, Muslim, Protestant, Traditional/Animist, No Religion and Other (base)	v130
Ethnicity	Bobo (base), Dioula, Fulfuldé/Peul, Gourmatché, Gourounsi, Lobi, Mossi, Sénoufo, Touareg/Bella, Dagara, Bissa, Pays CEDEAO, Autres pays français, and Autre	v131
The relationship of the respondent to the household head	Head itself, Wife, Daughter, Daughter in law, Mother, Mother in law, Sister, Adopted/foster child, and Not Related (base)	hv101
Age range of respondents	15-19 years (base), 20-24 years, 25-29 years, 30-34 years, 35-39 years, 40-44 years, and 45-49 years	age
Age ranges of household heads	16-30 years (base), 31-45 years, 46-60 years, 61-75 years, and over 75 years	hage
Gender of respondents	Man (base), and Women	hv104
Gender of household heads	Man (base), and Women	hv219
Education level of respondents	No education (base), Up to completed secondary school, and Higher education	educ
Education level of partner of respondent	No education (base), Up to completed secondary school, and Higher education	peduc
Education level of household head	No education (base), Up to completed secondary school, and Higher education	heduc
Pregnancy status of female respondents	Currently pregnant, and not pregnant (base)	V213
Frequency of the respondent reading newspapers	Not at all (base), Less than once a week, and At least once a week	v157
Frequency of the respondent listening to radio	Not at all (base), Less than once a week, and At least once a week	v158
Frequency of the respondent watching television	Not at all (base), Less than once a week, and At least once a week	v159

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Literacy	No ability to read sentence (base), Ability to partially read sentence, and Ability to read whole sentence	v155
Person deemed to have the final say in the family on making large household purchases	Respondent alone (base), Respondent and husband/partner, Husband/partner alone, Someone else, and Other	v743b
Person deemed to have the final say in the family on what to do with income	Respondent alone (base), Respondent and husband/partner, Husband/partner alone, Someone else, and Other	v743a
Number of wives of household head	0 (base), 1, 2, and over 3 additional wives	wives
Job category of the respondent	Agricultural (base), Sales, Skilled, and Other	working
Job category of the respondent's partner	Agricultural (base), Sales, Skilled, and Other	pworking
Number of trips the respondent has done within the last year	Min: 0 - max 2	numberoftrips

Table 5: Independent variables used for the determination of socio-demographic and cultural factors

Economic characteristics:

Independent Variable	Variable description	Name of variable in dataset
Wealth index	Poorest (base), Poor, Middle, Rich, and Richest	hv270

Table 6: Independent variables used for the determination of economic characteristics

Household characteristics:

Independent Variable	Variable description	Name of variable in dataset
The total number of people living in the same household	Min: 1 - max 53	vl36, hv009
Number of mosquito bednets in the household	Min: 0 - max 10	hml1
Age of the mosquito bednet	0-6 months (base), 7-12 months, 13-24 months, 25-36 months, and over 36 months	ageofbednet
Number of rooms used for sleeping in the household	Min: 0 - max 22	hv216
Household ownership of television	Yes, and no (base)	hv208
Household ownership of radio	Yes, and no (base)	hv207
Household ownership of mobile phone	Yes, and no (base)	hv243a
Household ownership of landline	Yes, and no (base)	hv221
Total number of household members	NB: number of usual residents plus the number of visitors who slept in the house the previous night that were listed in the household schedule	hv002
Total number of children resident in the household and aged 5 and under	Min: 0 - max 13	hvo14

Table 7: Independent variables used for the determination of household characteristics

Variables related to use of healthcare:

Independent Variable	Variable description	Name of variable in dataset
Woman visited health facility in last 12 months	Yes (base), and Not a big problem	v394
Geographic distance to health facility is perceived as an issue	Yes (base), and Not a big problem	v467d
Getting the money needed for a treatment is perceived as an issue	Yes (base), and Not a big problem	v467b
Respondent not wanting to go alone to health facility	Yes (base), and Not a big problem	v467c
Number of deceased children of female respondent	Min: 0 - max 12	deadchildren
Number of antenatal visits in the last 12 months	Min: 0 - max 12	antenatal
Delivery in 12 months prior to interview	Yes (base), and no	recentlymom
Radio as alternative sources of health information	Yes (base), and no	s112a
Television as alternative sources of health information	Yes (base), and no	s112b
Community health worker as alternative sources of health information	Yes (base), and no	s112d
Personal health as alternative sources of health information	Yes (base), and no	s112g
Friends or neighbours as alternative sources of health information	Yes (base), and no	s112l

Table 8: Independent variables used for the determination of healthcare characteristics

The descriptive statistics for the independent variables for the household (HR), household member (PR), women (IR), and children (KR) recodes can be found in the Appendix (Section o).

8.1.3 Empirical analysis – models

Three different models were used for the study of the research questions lined out above based on the type of outcome variable analysed:

- A discrete choice (logit) model was employed to analyse the behaviour of different units inside the household whenever the dependent variable is binary;
- An ordered logistic model was utilised when the choice of the unit of observation implies some clear ranking amongst the available discrete options;
- A count data model was applied when the dependent variable presents the possibility of a clear ranking of its options and the variable itself belongs to the positive integer domain.

Sample-based inferences about the population are only valid if the sample data are representative of the population. In order to avoid bias, the author applied the correct sample weights and accounted for different strata in sampling.

Moreover it was ensured that all the standard errors are robust in terms of the Huber-White estimator for the variance/covariance matrix.

Stata 14.0 (Stata Corporation, College Station, TX, USA) was used for the analysis.

Discrete choice (logit) model

In order to validate our hypothesis on the correlation between socio-demographic characteristics and the outcome variables of interest, the following linearized model was used for the unobserved variable $outcome_i$ *:

$$outcome_i = \eta_0 + \sum_{k=1}^K \gamma^k family_i^k + \sum_{j=1}^J x_i^j \alpha^j + \varepsilon_i$$

Where the proxy $outcome_i$ is a binary variable predicting when the latent $outcome_i$ * crosses a certain threshold. The vector **family** = [**family**¹ ... **family**^k ... **family**^K] contains all the independent variables relative to the enforcing characteristics of the household, the object of this study. The vector $x = [x^1 \dots x^k \dots x^K]$ collects all the possible control variables relative to all the determining characteristics (e.g. socio-demographic), which are described in Section 8.1.2. The ε_i is a continuously distributed variable which is independent of the set of covariates and follows a logistic distribution.

The regression coefficients $[\gamma^k, \alpha^i]$ were interpreted along the same line of linear models, with the caveat that the right-hand-side of the equation above does not include a conditional mean, but a logit function. The logit function links the measure of probability $\pi_i = P(outcome_i = 1 | \mathbf{family}_i, \mathbf{x}_i)$ to a function of our independent variables of interest:

$$logit(\pi_i) = \log \frac{\pi_i}{1 - \pi_i} = \sum_{k=1}^K \gamma^k family_i^k + \sum_{j=1}^J x_i^j \alpha^j$$

The logit function has a double purpose: linearizing the model, such that the model is a linear combination of the independent variables of interest, as well as constraining the parameters to change in a range between 0 and 1. Thus, $[\gamma, \alpha^i]$ captures the variation in the logit of the probability associated with a unit change in the j-th independent variable holding all other independent variables constant.

The results, however, were not presented as logit variations in Section 8.2, but in terms of probability variation. This allows for a better understanding of the problem. Nonetheless, it also required to calculate the following derivative:

$$\frac{\partial \pi_i}{\partial family_i^k} = G \left(\sum_{k=1}^K \gamma^k family^k + \sum_{j=1}^J x_i^j \alpha^j \right) \gamma = \pi_i (1 - \pi_i) \gamma^k$$

Where γ^j defines the sign of the derivative and the derivative itself depends on the values of the other independent variables at a specific point. On the other hand, when dealing with a discrete variable, the partial effect from changing the status of the discrete variable, holding all the other variables fixed is given by:

$$G \left(\gamma^k + \sum_{k=1}^{k-1} \gamma^k family^k + \sum_{k=k+1}^K \gamma^k family^k + \dots \right) - G \left(\sum_{k=1}^{k-1} \gamma^k family^k + \sum_{k=k+1}^K \gamma^k family^k + \dots \right)$$

In addition, in this case the expression depends on all other values of the other independent variables.

Ordered logit models

Some of the outcomes can be ordered in a clear ranking . In that case, the use of a ordered logistic regression was deemed as a more suitable model for analysis. Similarly to the logit model, the linearized model was defined as:

$$moutcome_i = \sum_{k=1}^K \gamma^k family_i^k + \sum_{j=1}^J x_i^j \alpha^j + \varepsilon_i$$

where $moutcome_i$ is a discrete ordered proxy variable (increasing values). This proxy variable changes status when the unknown variable $moutcome_i$ * crosses different unknown cut points, δ :

$$moutcome_i = j \text{ if } \delta_{j-1} < moutcome_i \leq \delta_j$$

with $j = 1, 2, \dots, J$. Given the logit assumption for the error term ε_i , it is straightforward to derive the conditional distribution of $moutcome_i$ given the provided set of independent variables. For the case j the response probability was given by:

$$\begin{aligned}
 \pi_i^j &= P(\text{outcome}_i = j | \mathbf{family}_i, \mathbf{x}_i) = P(\delta_j < \text{outcome}_i \leq \delta_{j+1} | \mathbf{family}_i, \mathbf{x}_i) \\
 &= \\
 &= G\left(\delta_{j+1} - \sum_{k=1}^K \gamma^k \text{family}_i^k + \sum_{j=1}^J \mathbf{x}_i^j \alpha^j\right) - G\left(\delta_j - \sum_{k=1}^K \gamma^k \text{family}_i^k + \sum_{j=1}^J \mathbf{x}_i^j \alpha^j\right)
 \end{aligned}$$

and it is verifiable that the sum over J is equal to 1. Moreover, when $j = 1$ the previous binary logit model was used as a subcase:

$$\begin{aligned}
 P(\text{outcome}_i = 1 | \dots) &= 1 - P(\text{outcome}_i = 0 | \dots) \\
 &= G\left(\sum_{k=1}^K \gamma^k \text{family}_i^k + \sum_{j=1}^J \mathbf{x}_i^j \alpha^j - \delta_1\right)
 \end{aligned}$$

hence $-\delta_1$ is the intercept inside G . This was the main motivation to drop the constant term from the original linearized model. Moreover, for this type of model the results were presented in terms of marginal effects in Section 8.2. In fact, also in the case of the ordered logistic model, it was possible to calculate the numerical derivatives for continuous variables as follows:

$$\frac{\partial \pi_i^j}{\partial \text{family}_i^k} = [G(\delta_{j+1} - \dots) - G(\delta_j - \dots)] \gamma^k$$

This term describes the marginal effect of an increase in a regressor k on the probability of selecting and alternative j . Each unit increase in the independent variable increases or decreases the probability of selecting alternative j by the marginal effect expressed in terms of percentage. However, for the ordered logistic model the sign of the coefficient term γ^k uniquely defines the direction of the marginal effect for the extreme options 0 and J only. For ulterior options the value of $[G(\delta_{j+1} - \dots) - G(\delta_j - \dots)]$ is ambiguous due to the symmetry of the logistic distribution. Moreover, the intercept points δ_j play an important role in defining the magnitude of the total marginal effect.

Count data model

When the expected outcome is a count variable which assumes only positive integer values, the normality assumption is likely to fail. In this case, a better distributional assumption for the independent variable is represented by the poisson distribution. During the analysis, for such variables, a negative binomial regression model, a generalization of the poisson distribution, was applied and the following linear model was supposed for the conditional mean:

$$coutcome_i = \eta_0 + \mathbf{family}_i \gamma + \sum_{j=1}^J \mathbf{x}_i^j \alpha^j + \varepsilon_i = \ln \lambda_i + \ln u_i$$

where the disturbance e_i captures crosssectional heterogeneity. The term λ_i is the event rate, also called the rate parameter taken from the Poisson distribution. This parameter measures the average number of positive events in an interval. The term u_i is an individual, unobserved effect meant to model dispersion of data. The negative binomial distributed error term allows for different values of the conditional mean and variance, a feature not provided by the Poisson distribution itself. Hence, the unconditional distribution $\pi(coutcome_i | \mathbf{family}_i, \mathbf{x}_i)$ is a mixture model given by the combination of the conditional distribution $\pi(coutcome_i | \mathbf{family}_i, \mathbf{x}_i, u_i)$ which is poisson and a well behaved distribution for u_i , $g(u_i)$.

Also in this third case, the interpretation pattern of coefficients was not different from that applied to the linear regression model, since a log-linear model was estimated. A unit increase or decrease of an independent variable k , keeping the others fixed, respectively increases or decreases the dependent variable $coutcome_i$ by γ^k .

8.2 Results

8.2.1 Determinants influencing the ownership of bednets in Burkina Faso

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Factors influencing bednet ownership at household level

BEDNET OWNERSHIP - HR	2003	2010
AREA:		
Urban	-0.093** (0.045)	-0.073** (0.030)
HH CHARACTERISTICS:		
# hh members	0.010*** (0.003)	-0.005* (0.003)
# of children < 5 yrs	-0.005 (0.009)	0.032*** (0.008)
HH OWNS RADIO:		
Yes	0.102*** (0.029)	0.051*** (0.020)
HH OWNS TV:		
Yes	0.144*** (0.044)	0.079*** (0.030)
HH OWNS MOBILE:		
Yes		0.051** (0.020)
HH WEALTH:		
Poorer	-0.016 (0.038)	-0.025 (0.026)
Middle	0.034 (0.039)	0.004 (0.028)
Richer	0.070* (0.039)	0.008 (0.029)
Richest	0.113** (0.055)	0.094** (0.038)
HH HEAD EDUCATION:		
Up to completed secondary	0.047 (0.032)	0.076*** (0.025)
Higher	0.349*** (0.116)	0.047 (0.190)
RADIO BROADCASTED IN HH:		
Less than once a week	0.004 (0.032)	0.060** (0.024)
At least once a week	-0.009 (0.029)	0.069*** (0.021)
Almost every day	0.059* (0.031)	
DISTANCE TO H. FACILITY:		
Not a big problem	-0.038 (0.023)	0.037* (0.019)
COST TO REACH H. FACILITY:		
Not a big problem	0.072*** (0.022)	0.012 (0.020)
N	3193.000	3530.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 9: Determinants influencing the ownership of bednets at household level for 2003 and 2010 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

Given the typical Burkinabé household structure and way of living (see Chapter 7), bednet ownership was evaluated at household level rather than individual level. Further, the data was analysed only for 2003 and 2010 due to a major mass distribution of bednets just before the 2014 survey, which would have biased the results.

The area of residence seems to be associated with bednet ownership. Urban households were 7.3% (9.3% in 2003) less likely to have bednets than rural households. This may be due to two aspects: independent free distribution campaigns are more likely to target remote and hence rural areas. People in urban areas may have more access to other similar and alternative prevention measures such as window shields.

Bednet ownership was positively related to wealth-associated factors such as radio, TV, as well as mobile phone ownership. The richest wealth quintile was 9.4% (11.3% in 2003) more likely to own a bednet than the poorest one. Furthermore, in 2010 listening to radio had an influence on bednet ownership compared to household members not listening to radio. In fact, in 2014, people listening to radio less than once a week were 6.0% more likely, and individuals listening to radio at least once a week 6.9% more likely, to own bednets compared to respondents not listening to the radio at all. This is probably due to the increased number of awareness programmes run by the national and local radios throughout the country as part of the PNLP program.

In 2010 the number of children under 5 years living in the household also had an impact on the bednet ownership. Each additional child was associated with a 3.2% increase in the probability of owning a bednet. This was probably due to the PNLP policy to disburse free bednets to either pregnant women or women with small children during visits taken place at health facilities. The same is true for the number of household members in 2003, but the 2010 data seems to contradict the one of 2010, suggesting a possible change of trend. Further research would be needed to investigate this phenomenon.

The education of the chief of the household influences the rate of bednet ownership in a positive way. In 2003 households with household heads having attended higher

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education were 34.9% more likely to have bednets in their homes compared to households where the head had no education. In 2010 households with chiefs with up to a completed secondary education had a 7.6% higher chance of owning a bednet compared to families with an uneducated head.

While in 2003 the cost to reach a health facility played a role in the bednet ownership, this effect was lost by 2010. This is probably due to the fact that in the past it was a governmental policy to, whenever possible, hand out free bednets to pregnant women attending antenatal visits at health facilities. This is still the case, but the number of bednets made locally available to the population through NGOs has increased considerably. Furthermore, it is also possible to purchase them for a fraction of the price at local markets and hence the cost to reach health facility no longer plays a major role. This hypothesis is strengthened by the fact that in 2010 the distance to the health facility plays only marginal role.

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8.2.2 Determinants influencing the use of bednets in Burkina Faso

Factors influencing general bednet use

BEDNET USE - PR	2003	2010	2014
AREA:			
Urban	-0.021 (0.021)	0.041** (0.018)	0.007 (0.036)
BEDNET AGE RANGE:			
7-12 m	-0.138*** (0.036)	-0.066*** (0.018)	0.045 (0.033)
13-24 m	-0.115*** (0.032)	-0.074*** (0.016)	0.018 (0.031)
25-36 m	-0.442*** (0.032)	-0.270*** (0.025)	-0.081 (0.056)
>36 m	-0.119*** (0.027)	-0.005 (0.015)	0.034 (0.041)
RESP. AGE RANGE:			
16-30 y	-0.082*** (0.016)	-0.177*** (0.012)	-0.084*** (0.015)
31-45 y	-0.026 (0.021)	-0.195*** (0.016)	-0.037 (0.043)
46-60 y	-0.072*** (0.022)	-0.283*** (0.018)	-0.108** (0.046)
61-75 y	0.020 (0.037)	-0.270*** (0.026)	-0.138** (0.054)
>75 y	0.017 (0.088)	-0.250*** (0.046)	-0.166** (0.073)
RESP. GENDER:			
Female	0.003 (0.010)	0.035*** (0.009)	0.083*** (0.015)
HH HEAD AGE RANGE:			
31-45 y	-0.060* (0.032)	-0.020 (0.021)	-0.039 (0.032)
46-60 y	-0.069** (0.034)	-0.029 (0.023)	-0.058 (0.035)
61-75 y	-0.168*** (0.034)	-0.069** (0.027)	-0.076** (0.034)
>75 y	-0.154*** (0.048)	-0.025 (0.038)	-0.039 (0.048)
HH HEAD GENDER:			
Female	0.160*** (0.028)	0.166*** (0.017)	0.087*** (0.024)
HH HEAD EDUCATION:			
Up to completed secondary	0.021 (0.021)	0.058*** (0.014)	
Higher	0.110 (0.085)	-0.028 (0.065)	
HH CHARACTERISTICS:			
# hh members	-0.017*** (0.001)	-0.024*** (0.002)	-0.025*** (0.004)
# bednets	0.115*** (0.007)	0.125*** (0.006)	0.101*** (0.006)

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BEDNET USE - PR (cont.)	2003	2010	2014
RELATION TO HH HEAD:			
Head	0.591*** (0.036)	0.506*** (0.026)	0.355*** (0.039)
Wife or husband	0.363*** (0.033)	0.557*** (0.024)	0.348*** (0.041)
Son/daughter	0.131*** (0.026)	0.169*** (0.024)	0.157*** (0.035)
Son/daughter-in-law	0.219*** (0.037)	0.561*** (0.065)	0.305*** (0.053)
Grandchild	0.034 (0.031)	0.141*** (0.036)	0.134*** (0.043)
Parent	0.046 (0.056)	0.280*** (0.050)	0.162** (0.065)
Parent-in-law	0.171** (0.073)	0.110 (0.079)	0.076 (0.124)
Brother/sister	0.079* (0.044)	0.060 (0.055)	0.187*** (0.068)
Adopted/foster child	0.015 (0.084)	0.113*** (0.039)	-0.027 (0.092)
Not related	0.007 (0.031)	0.063 (0.045)	0.049 (0.080)
N	10984.000	19782.000	8324.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 10: Determinants influencing the use of bednets at population level for 2003, 2010, and 2014 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

The analysis indicates that in 2010 the area of residence was associated with bednet use. People living in urban areas had 4.2% higher probability to use bednets than those in rural areas. This association was not present in other years.

The age of the bednet is also strongly correlated with its use. The older the bednet, the lower the use. In 2003 a 7 to 12 months old bednet was used 13.8% less than an almost new one (0 to 6 months), a 13 to 24 months one 11.5% less, and a 25 to 36 months one 44.2% less. This correlation faded over the years resulting in a non-relevant association in 2014. This could be due to the improved quality and duration of the new generation bednets, but still shows that the quality of the bednet plays a major role in its use.

Elderly people tend to use bednets less than younger ones and compared to children. The 2003 data shows little correlation, but this becomes stronger over the years. Thus, 16 to 30 year olds were 17.7% (8.4% in 2014) less likely and people over 75 years of age 25.0% (16.6% in 2014) more unlikely to sleep under bednets

compared to young adults. This is probably due to two major factors. First, children and young adults are the most vulnerable age group to the disease, and hence over the years government campaigns have mainly focussed on that age group sleeping under bednets. Furthermore, the generation's gap in understanding, accepting and adopting new technologies is a well-known sociological factor.

Especially in 2003 there was a negative association also with ageing household heads. The older the family chief, the less likely it was for other members of the household to sleep under bednets. Respondents with a household head between 31 and 45 years were 6.0% less likely to sleep under a bednet, while for household members with a 61 to 75 years old family chief it was 16.8% less likely compared to households with 16 to 30 years old leaders. Similar patterns are observed also for 2010 and 2014 but are statistically less or not significant.

While older population members seemed to be less likely to use bednets, women were more likely to sleep underneath them than men. In fact, over the years, women have become increasingly more likely to sleep under bednets than men. In 2010, women were 3.4% more likely to use bednets than men, rising to 8.3% in 2014.

Female household heads were extremely important for the use of bednets in families. When women led the household, the other members were 16.0%, 16.6%, and 8.7% respectively in 2003, 2010, and 2014 more likely to use bednets compared to family units with male leaders.

In 2010, the education level of the household lead seemed to play a role, with family members being 5.8% more likely use bednets if the household head had up to a completed secondary education.

Members of larger families were less likely to sleep under bednets. This correlation is true for each of the three years and increases over time. Each additional member of the family reduces the probability of the family members using a bednet by 1.7% in 2003, 2.4% in 2010, and 2.5% in 2014. This is probably due to an increased cost of living for larger families and hence the economic power to purchase several bednets decreases, as well as the fact that only a limited number of people can use a bednet at once.

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The number of bednets owned and available within a household obviously increased the probability that respondents would sleep underneath one. Each additional bednet owned within the household increases the probability of use by 11.5% in 2003, 12.5% in 2010, and 10.1% in 2014.

The relationship with the household head and hence the hierarchical social structure within the family also has a significant impact on the use of bednets. This seems to follow the hierarchical structure within a family. This sociological factor seems also to remain unvaried over the years, showing that is deeply rooted in the Burkinabé culture and way of living.

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Factors influencing women's bednet use

BEDNET USE - IR	2003	2010
HH CHARACTERISTICS:		
# bednets	0.078*** (0.010)	0.023*** (0.004)
# hh members	-0.012*** (0.003)	-0.007*** (0.001)
RESP. AGE RANGE:		
20-24 yrs	0.009 (0.048)	0.057** (0.023)
25-29 yrs	0.062 (0.044)	0.076*** (0.023)
30-34 yrs	0.088* (0.053)	0.067*** (0.023)
35-39 yrs	0.080 (0.055)	0.074*** (0.025)
40-44 yrs	0.095 (0.062)	0.073*** (0.025)
45-49 yrs	0.159*** (0.052)	0.061* (0.032)
RESP. RECENTLY MOM:		
Delivery in last 12m	-0.006 (0.021)	0.015** (0.007)
HH HEAD GENDER		
Female	0.140*** (0.039)	0.021 (0.016)
RELATION TO HH HEAD:		
Head	-0.297 (0.293)	0.311*** (0.095)
Wife	0.087 (0.078)	0.336*** (0.089)
Daughter	-0.146 (0.177)	-0.009 (0.131)
Daughter-in-law	-0.009 (0.076)	0.262*** (0.089)
Granddaughter	-0.205 (0.335)	
Mother-in-law		-0.038 (0.251)
Sister	-0.279 (0.187)	-0.274 (0.199)
Not related	-0.008 (0.161)	0.255*** (0.098)
HH HEAD # WIVES:		
1 additional wife	-0.094*** (0.024)	-0.077*** (0.009)
2 additional wives	-0.106** (0.044)	-0.084*** (0.017)
3 additional wives	-0.064 (0.071)	-0.091*** (0.031)
RESP. VISITED H. FACILITY:		
Yes	0.052*** (0.017)	0.004 (0.007)

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BEDNET USE - IR (cont.)	2003	2010
PARTNER EDUC.:		
Up to completed secondary	0.054* (0.032)	-0.014 (0.017)
Higher	0.109** (0.043)	0.027 (0.020)
BEDNET AGE RANGE:		
7-12 m	-0.039 (0.031)	-0.016* (0.009)
13-24 m	-0.066** (0.031)	-0.004 (0.009)
25-36 m	-0.134* (0.075)	-0.020 (0.018)
>36 m	-0.047* (0.024)	-0.009 (0.009)
PARTNER JOB:		
Sales	0.089*** (0.026)	-0.006 (0.011)
Skilled	-0.289** (0.117)	-0.012 (0.015)
Other	0.057* (0.030)	-0.001 (0.016)
N	1535.000	5565.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 11: Determinants influencing the use of bednets at women level for 2003 and 2010 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

Given that amongst the whole Burkinabé population women played a crucial role in the uptake of bednets, the author decided to analyse also which factors have an influence on their decision to use bednets.

In this analysis, the more bednets were present in the household, the more women were likely to sleep under one, while an increase in household members decreased slightly their probability of using one. Furthermore, in 2003, the gender of the household head played a major role, with women being 14% more likely to use bednets, if the head of the family was also a woman.

In 2010 especially, women in their reproductive age were more likely to sleep under bednets than younger females. In fact, women between 25 and 29 years had a 7.6% higher probability of using a bednet compared to younger females aged 15 to 19.

This was strengthened by the fact that women who gave birth in the last 12 months before the survey date had 1.5% higher chance of sleeping under a bednet compared to women without deliveries in the past 12 months.

Also in 2010, the family hierarchical structure and the relationship of women to the household leader played a crucial role in bednet use. The head, his wife and the daughter in law seem to be the most likely to sleep under the nets, reinforcing the sociological importance of the head and the fact that women in reproductive ages are more likely to use the nets.

Whether a woman is the first, second or third wife of the household head also influences the likelihood of sleeping under the bednet. The higher the rank, the less likely the chance of using the net. In 2010 (2003) the first additional wife was 7.7% (9.4%), the second 8.4% (10.6%), and the third (or more) 9.1% less likely to sleep under a net than the first wife. This fact strengthens even more the hypothesis that bednet use is linked to the hierarchical family structure and the sociological importance individuals are given within it.

In 2003 women with educated partners were more likely to sleep under bednets. In fact, women with a partner educated up to completed secondary school were 5.4% more likely to use a bednet than a woman with a partner without education. The probability goes up to 10.9% for women with a companion with a higher education. Also this indicates the importance of the value attributed to woman within the social structure.

Not just education, but also the type of job performed by a woman's husband seemed to be important in 2003. The data seems less coherent, though, suggesting the need for further investigation.

Even if it is less statistically significant in comparison to the data for the global population, also for women the bednet age seems to have a negative impact on use, while the association is stronger in 2003 compared to 2010, suggesting that the improved quality of the new bednets has an impact on their use. In fact, in 2003 women with 25 to 36 months old bednets were 13.4% less likely to use them than women with a bednet up to 6 months old.

Finally, in 2003 women who had visited a health facility in the 12 months before the survey were 5.2% more likely to use bednets as prevention measure compared to women who had not visited the facility. This could be linked to the fact that in 2003

one of the few ways to get a free bednet and to receive messaging around it was through health facilities.

Factors influencing children's bednet use

BEDNET USE - KR	2003	2010
HH CHARACTERISTICS:		
# HH members	-0.015*** (0.004)	-0.010*** (0.002)
# bednets	0.162*** (0.016)	0.064*** (0.009)
RELATION TO HH HEAD:		
Head	0.463** (0.186)	0.069 (0.085)
Wife	0.366*** (0.107)	0.028 (0.068)
Daughter	0.232** (0.116)	-0.201** (0.102)
Daughter-in-law	0.259** (0.104)	0.027 (0.081)
Granddaughter	0.208 (0.190)	
Mother-in-law		-0.383*** (0.145)
Sister	0.151 (0.252)	-0.019 (0.118)
Not related	0.108 (0.241)	0.087 (0.084)
HH HEAD EDUCATION:		
Up to completed secondary	0.009 (0.059)	-0.012 (0.025)
Higher	0.267** (0.104)	-0.103 (0.082)
HH HEAD # WIVES:		
1 additional wife	-0.091*** (0.031)	-0.022 (0.016)
2 additional wives	-0.143*** (0.052)	-0.084*** (0.032)
3 additional wives	-0.155* (0.087)	0.030 (0.046)
RESP. EDUCATION:		
Up to completed secondary	0.035 (0.035)	0.020 (0.018)
Higher	0.309*** (0.075)	-0.127 (0.102)
RESPONSIBLE FOR LARGE EXPENSES:		
Respondent and husband/partner	0.021 (0.058)	0.092** (0.046)
Husband/partner alone	0.016 (0.057)	0.092** (0.045)
Someone else	0.067 (0.124)	-0.097 (0.102)
Other	0.100 (0.189)	0.101 (0.129)

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BEDNET USE - KR	2003	2010
DISTANCE TO H. FACILITY:		
Not a big problem	-0.008 (0.025)	-0.026** (0.012)
N	3222.000	9505.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 12: Determinants influencing the use of bednets at children level for 2003 and 2010 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

Consistent with the previous analysis, children in 2003 and 2010 were less likely to sleep under bednets the larger the household, and are more likely to use them when there were more bednets available in the house. In fact, each additional household member decreased the probability of a child sleeping under a bednet by 1.5% in 2003 and 1% in 2010, while for each additional bednet, the same probability increased by 16.2 in 2003 and 6.4% in 2010.

In 2003 the hierarchical family structure had a huge influence on whether children under 5 years of age sleep under bednets. The closer the relationship of the mother to the household head, the more probable it was for a child to use the bednet. If the mother of the child was also the head of the family, then a child had 46.3% more chance to sleep under a bednet than the child of someone not related to the household. The probability fell to 36.6% for the child of a wife of the chief of the family and to 25.9% if it is the nephew of the leader. In 2010 the situation is similar, but the data statistically not relevant.

The sociological importance given to the family structure is reinforced by the fact that in 2003 children of the first, second, and third additional wife had respectively 9.1%, 14.3% and 15.5% less chance to sleep under a bednet than children of the first wife. Also, in this case the data for 2010 showed a similar trend but the results were not statistically relevant besides for the second additional wife.

In 2003 the education of the household head and of the mothers also seemed to play a role, with children of chiefs and mothers with a higher education being respectively 26.7% and 30.9% more likely to use a bednet compared to those with uneducated family leads and mothers. This trend could not be confirmed for 2010.

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In 2010 the person responsible for large expenses within the family as well as the distance to the health facility seemed to play a role, on whether children would sleep under a bednet. This data, though, does not seem to be coherent with the rest of the data, suggesting that more research might be needed to enlighten those relationships.

8.2.3 Determinants influencing the uptake of Intermittent Preventive Therapy in Burkina Faso

Factors influencing the uptake of Intermittent Preventive Therapy during Pregnancy (IPTp)

IPTp UPTAKE - IR	2010	2014
AREA:		
Urban	0.065*** (0.023)	-0.007 (0.031)
RESP. AGE RANGE:		
20-24	0.004 (0.023)	0.287*** (0.023)
25-29	-0.017 (0.022)	0.345*** (0.025)
30-34	-0.020 (0.023)	0.326*** (0.035)
35-39	-0.055** (0.026)	0.218*** (0.031)
40-44	-0.088*** (0.030)	0.061** (0.027)
45-49	-0.110*** (0.040)	-0.084*** (0.023)
RESP. CHILD LOSS:		
# dead children	0.010** (0.005)	-0.007 (0.007)
RELATION TO HH HEAD:		
Head	0.108 (0.079)	0.069 (0.055)
Wife	0.110* (0.061)	0.264*** (0.038)
Daughter	0.053 (0.088)	-0.095*** (0.031)
Daughter-in-law	0.079 (0.068)	0.198*** (0.041)
Granddaughter		-0.048 (0.055)
Mother	0.253* (0.133)	-0.096 (0.084)
Mother-in-law	0.120 (0.130)	0.184* (0.104)
Sister	0.119 (0.162)	-0.076* (0.046)
Co-spouse		0.225 (0.195)
Other relative		
Adopted/foster child		-0.111 (0.068)
Not related	0.042 (0.085)	0.007 (0.083)

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IPTp UPTAKE - IR	2010	2014
HH HEAD AGE RANGE:		
31-45 yrs	0.003 (0.015)	0.004 (0.023)
46-60 yrs	0.029 (0.019)	-0.033 (0.029)
61-75 yrs	0.025 (0.025)	-0.121*** (0.035)
>75 yrs	-0.020 (0.055)	-0.092 (0.062)
HEALTHCARE AS SOURCE OF INFO:		
yes		0.184*** (0.024)
HH HEAD # WIVES:		
1 additional wife	-0.003 (0.014)	
2 additional wives	-0.066*** (0.025)	
3 additional wives	-0.030 (0.044)	
RESP. LISTENS TO RADIO:		
Less than once a week	0.085*** (0.016)	
At least once a week	0.070*** (0.015)	
RESP. VISITED H. FACILITY:		
Yes	0.041*** (0.013)	
DUE ANTENATAL VISITS:		
Visited	0.712*** (0.011)	
RESPONSIBLE FOR HEALTH EXPENSES:		
Respondent and husband/partner	-0.055** (0.026)	
Husband/partner alone	-0.007 (0.024)	
Someone else	-0.030 (0.061)	
Other	-0.264 (0.169)	
N	9336.000	7786.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 13: Determinants influencing the use of Intermittent Preventive Therapy (IPTp) for 2010 and 2014 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

For this analysis IPTp uptake was limited to at least one dose of SP/Fansidar. This medication was chosen because it is the sole IPTp drug recommended to Burkinabé pregnant women by both the WHO and the Burkinabé Ministry of Health (World

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Health Organisation (WHO), 2015, Ministère de la Santé du Burkina Faso and Direction Générale des Etudes et des Statistiques Sectorielles, 2014).

In 2010 women living in urban areas were 6.5% more likely to take at least one dose of IPTp during pregnancy compared to women living in rural areas. In 2014 this was no longer the case, suggesting a breakthrough of the medication to rural populations.

The age range of a woman also seems to have an impact on their IPTp uptake. While the 2010 data demonstrates only that women over 35 were less likely to take the medication compared to young women between 15 and 19 years of age, the 2014 data shows that there is an increase in probability until the age of 25 to 29 and then a slow decrease over time. In fact, women aged 25 to 29 were 35.5% more inclined to take IPTp compared to women between 15 and 19. This may be a consequence to the early marriage age in the Burkinabé society and the consequent fact that women tend to have children very early.

In 2010 the loss of each child increased the likelihood of a woman taking IPTp by 1%. By 2014, this did not appear to be the case. This might be due to the improved child mortality rates within the country and showed that other factors might be more important in influencing the uptake of IPTp.

Also in this case the family structures seem to play a role in the uptake of IPTp prevention, with wives of the household head playing a crucial role. For example, wives of the household leader were 26.4% more likely to take at least one dose of SP/Fansidar, while the daughters-in-law only 19.8% more likely compared to women external to the family. This effect seems to be less pronounced than for bednets, but is still relevant, marking once again the importance of the family hierarchy in the Burkinabé society and how this reflects on the adoption of malaria elimination tools.

In 2010, this was also highlighted by the fact that a woman is less likely to take IPTp if she is not the first wife of her husband, with the second additional wife being 6.6% less destined to take IPTp compared to the first wife.

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The household head age also seems to have an impact. Women with a 61-75 years old household leader were 12.1% less likely to take IPTp compared to women with young chiefs. In this case, while the trend is confirmed, the statistical relevance of the data is weak.

IPTp uptake seemed to be more frequent when women are the sole person responsible for health expenses in the family. In fact, women sharing the responsibility with their partner were 5.5% less likely to take at least one dose of IPTp.

Women listening to radio even sporadically were 8.5% more likely to take at least one dose of IPTp. This is probably related to the increased amount of health and family planning spots run through the radio as part of the PNL strategy.

In 2010, the channel through which a woman received information on health prevention measures also impacted on her probability to take IPTp during her pregnancy. In fact, women with a direct link to health facilities as a primary source of facts were 18.4% more likely to take IPTp.

Furthermore, pregnant women who attended antenatal visits were 71.2% more likely to take at least one dose of IPTp compared to women not going to those prevention visits. This seems logical, given that whenever possible doctors are supposed to hand out IPTp during antenatal visits. But simply attending a health facility within the last 12 months without attending an antenatal visit also had a positive impact of 4.1% compared to women who did not visit at all a health facility.

Factors influencing the uptake of multiple Intermittent Preventive Therapy (IPTp) doses

IPTp doses - IR	2010	IPTp doses – IR (cont.)	2010
DISTANCE TO GET MEDICAL HELP: NOT BIG PROBLEM		RESP. NUMBER OF TRIPS	
0 dose	-0.075*** (0.020)	0 dose	0.066* (0.038)
1 dose	0.056*** (0.015)	1 dose	-0.050* (0.029)
2 doses	0.018*** (0.005)	2 doses	-0.014 (0.009)
3 or more	0.002*** (0.001)	3 or more	-0.002 (0.001)
RESP. LISTENS TO RADIO: AT LEAST ONCE A WEEK		PARTNER EDUC.: UP TO SECONDARY	
0 dose	-0.059*** (0.021)	0 dose	0.050** (0.024)
1 dose	0.043*** (0.015)	1 dose	-0.036** (0.017)
2 doses	0.015** (0.006)	2 doses	-0.013* (0.007)
3 or more	0.002** (0.001)	3 or more	-0.001* (0.001)
RESPONSIBLE FOR HEALTH EXPENSES: RESPONDENT AND HUSBAND/PARTNER		PARTNER EDUC.: HIGHER	
0 dose	-0.043** (0.022)	0 dose	0.065** (0.031)
1 dose	0.031** (0.015)	1 dose	-0.049** (0.024)
2 doses	0.011* (0.006)	2 doses	-0.014** (0.006)
3 or more	0.001* (0.001)	3 or more	-0.002** (0.001)
		N	6445.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 14: Determinants influencing the number of Intermittent Preventive Therapy (IPTp) doses taken during pregnancy for 2010 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

The WHO recommends pregnant women in hyper-endemic countries like Burkina Faso take at least 3 IPTp throughout the 9 months of pregnancy (World Health Organisation (WHO), 2015), hence the author decided to see whether there were any factors that influenced the number of IPTp doses taken by pregnant women.

Where the distance to a health facility was not a big issue for women, the probability of taking one dose of IPTp did increase, but this did not seem to be a relevant factor for the uptake of further doses. In fact, when the distance was not a problem for

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women, the probability of her not taking a dose of IPTp decreased by 7.5%, while the likelihood of taking one dose increased by 5.6%. However, the probability of taking two doses compared to one increased only by 1.8% and between two and three or more doses only by 0.2%.

Whether the respondent listened to radio at least once a week reduced the probability of not taking IPTp by 5.9%, but increased the likelihood of taking one dose by 4.3%, while the probability of taking two doses compared to one increased only by 1.5% and between two and three or more doses only by 0.2%.

The equivalent was true for women taking decisions on health expenses jointly with their husband. It decreased the probability of not taking the preventive treatment by 4.3% and the probability of taking one dose was increased by 3.1%. The effect diminished for the next doses with the likelihood of taking two doses compared to one dropping to 1.1% and to 0.1% between two and three or more doses.

The exact opposite effect was achieved by the number of trips a women had done within the past 12 months. Non sedentary women were 6.6% more likely to not take even one dose of the IPTp and their travel schedule also decreased the likelihood of taking one dose by 5.0%, while the probability of taking two doses compared to one decreased only by 1.4% and between two and three or more doses only by 0.1%.

The same trend seemed to be true also for a woman's partner's education independently of the level (both up to secondary and higher education). This data contradicts previous statistics and would need further investigation.

Nevertheless, this analysis shows that all the relevant determinants that have an impact on whether a woman is prone to take IPTp during pregnancy or not, do not seem to be significant determinants of whether two or more doses are taken during the course of the pregnancy.

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Factors influencing the uptake of SP/Fansidar compared to other medications

IPTp Fansidar vs. other medication - IR	2010	2014
AREA:		
Urban	-0.056*** (0.021)	-0.005 (0.023)
HH:		
# hh members		0.004*** (0.002)
RESP. EDUCATION:		
Up to completed secondary	0.049** (0.024)	0.000 (0.016)
Higher	0.091 (0.100)	0.014 (0.084)
RESP. CHILD LOSS:		
# dead children	-0.014*** (0.005)	
HH WEALTH::		
Poorer	-0.014 (0.016)	0.046** (0.023)
Middle	-0.013 (0.017)	0.012 (0.024)
Richer	-0.028 (0.019)	0.022 (0.027)
Richest	0.009 (0.028)	-0.010 (0.036)
DUE ANTENATAL VISITS:		
Visited	-0.518*** (0.079)	
HH HEAD # WIVES:		
1 additional wife	0.007 (0.014)	
2 additional wives	0.051** (0.025)	
2 additional wives	0.040 (0.045)	
RESP. LISTENS TO RADIO:		
Less than once a week	-0.068*** (0.015)	
At least once a week	-0.065*** (0.015)	
Respondent and husband/partner	0.058** (0.026)	
Husband/partner alone	0.009 (0.024)	
Someone else	0.002 (0.058)	
Other	0.234 (0.188)	

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IPTp Fansidar vs. other medication - IR	2010	2014
PARTNER JOB:		
Sales	0.006 (0.019)	
Skilled	0.052** (0.023)	
Other	0.023 (0.032)	
N	8258.000	3927.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 15: Determinants influencing the uptake of SP/Fansidar compared to other of Intermittent Preventive Therapy (IPTp) medications for 2010 and 2014 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

Despite SP/Fansidar being the recommended medication for IPTp, a significant proportion of the surveyed women mentioned that they took other types of medication for IPTp. Hence the author decided to understand if there were specific factors that led to the choice of a non-conventional medication.

The area of residence of a woman played a role in 2010, with women in urban areas being 5.6% less likely to take other medications. The difference may be due to the lack of availability of SP/Fansidar in rural areas of certain medications, or to a lower level of awareness of the medical protocols by rural doctors. The effect was lost in 2014, which would show that these disparities between the urban and rural cohorts were eliminated.

In 2014, for each other additional household member women were 0.4% more likely to take other medications. This might be due to the fact that larger households tend to be economically weaker.

In 2010, listening to radio, even if infrequently, seemed to reduce the likelihood of using alternative medications for IPTp, with listening to the radio once a week reducing the risk of taking the wrong medication by 6.5%. As mentioned for other technologies, this was probably due to the fact that the government has put increased efforts in channelling health messages through national and local radios.

Poorer women seemed to be also more likely to take other medications, but this trend is not confirmed by statistical relevance.

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In this case, the social structure played a role only through the wife's rank, as first wives were more likely to take the right medication. In fact, in 2010, a second additional wife was 5.1% more likely to take an alternative medication than a first wife.

Furthermore, women being jointly responsible for health expenses with their partners were 5.8% more likely to take alternative medications, compared to women solely owning that responsibility within the household.

In 2010, each child lost decreased the probability of taking the wrong medication decreased by 1.4%, suggesting a correlation between the two factors due to the fact that women might place more attention on prevention after such dramatic events.

In the same year, women attending antenatal visits were 51.8% less likely to take alternative IPTp medications. This is probably due to the fact that doctors are supposed to give SP/Fansidar for free during antenatal visits as part of the PNLP strategy.

Additionally, in 2010, women with any level of education were more inclined towards using the right medication. In fact, women with up to a completed secondary education were 4.9% more inclined to use the right product compared to women with no education.

All the other statistical relevant factors seem to be in contrast and discordant with the rest of the findings. This indicates that the factors leading to the uptake of other medications may not be explicable with those variables and further research would be needed to clarify them.

8.2.4 Determinants influencing the use of antimalarial drugs in Burkina Faso

Factors influencing the uptake of antimalarial medications for the treatment of fever in children

ANTIMALARIAL UPTAKE - KR	2010	2014
AREA:		
Urban	0.071* (0.043)	0.009 (0.059)
RESP. EDUCATION:		
Up to completed secondary	0.088* (0.052)	-0.006 (0.031)
Higher	0.495*** (0.124)	
RESP. WEALTH:		
Poorer	-0.056 (0.038)	-0.013 (0.038)
Middle	-0.011 (0.039)	0.095** (0.045)
Richer	-0.004 (0.041)	0.122*** (0.046)
Richest	0.095 (0.059)	0.198*** (0.070)
PARTNER JOB:		
Sales	0.081** (0.035)	
Skilled	0.141*** (0.052)	
Other	0.047 (0.071)	
HH HEAD EDUCATION		
Up to completed secondary	0.030 (0.060)	
Higher	0.431*** (0.147)	
RESPONSIBLE FOR LARGE EXPENSES:		
Respondent and husband/partner	-0.108 (0.079)	
Husband/partner alone	-0.125* (0.072)	
Someone else	-0.195 (0.212)	
Other	-0.386*** (0.136)	
HH OWNS LANDLINE:		
Yes	-0.140 (0.097)	0.346*** (0.115)
RESP. LISTENS TO RADIO:		
Less than once a week	0.067** (0.034)	
At least once a week	0.067** (0.030)	
RESP. VISITED H. FACILITY:		
Yes	0.089*** (0.030)	

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ANTIMALARIAL UPTAKE - KR (cont.)	2010	2014
CHWs AS SOURCE OF INFO:		
yes		0.089** (0.038)
HEALTHCARE AS SOURCE OF INFO:		
yes		0.065** (0.032)
N	2229.000	2214.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 16: Determinants influencing the uptake of antimalarial medications for the treatment of fever in children for 2010 and 2014 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

In 2010 children in urban areas were 7.1% more likely to have fever treated with antimalarials. Even if not statistically significant, the percentage was much reduced in 2014, showing that the disparity gap in availability between urban and rural areas was reduced.

In 2010 the education of the mother played a crucial role in the uptake of medications against malaria. In fact, a child with a mother who attended higher education was 49.5% more likely to have the fever treated with such a medication compared to children of women with no education. The same was true for the education of the chief of the household, which increased the likelihood by 43.1%.

In 2014 a child's family wealth had a huge impact on whether he or she would be treated with antimalarials. A child from a family in the middle, richer and richest wealth quintiles was respectively 9.5%, 12.2%, and 19.8% more likely to get fever treated with an antimalarial medication compared to children from families in the poorest wealth quintile.

The type of job held by the father also enhanced the likelihood of the children being treated with antimalarial medications. In 2010 children from men with a skilled job had a 14.1% greater chance of treatment compared to children with fathers working in the agricultural sector.

In 2014 the ownership of a landline within the household also seemed to raise the uptake of antimalarial medication as a remedy for fever in children living in the household, by 34.6% compared to households with no TV. This is possibly linked to the wealth and urban factors, as families that tend to own landlines also tend to be

wealthier and live in cities. Listening to radio of mothers also seemed to have a similar impact, but with a more moderate effect and an increase of 6.7%.

A child's probability of having fever treated with antimalarial medications increased by 8.9% in 2010, if the mother had visited a health facility within the last 12 months

Where the mothers retrieved their information on health related messages also played an important role in the uptake of the medication. In 2014 women with community health workers (CHWs) or a healthcare facility provider as such sources were respectively 8.9% and 6.5% more likely to have their children treated with antimalarials compared to women which did not utilise those information channels.

Further, women being jointly responsible for large expenses with their partners were 10.8% less likely to give their children antimalarials compared to women solely owning that responsibility within the household.

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Factors influencing the prompt uptake of antimalarial medications for the treatment of fever in children

PROMPT ANTIMALARIAL UPTAKE - KR	2010	2014
RESP. EDUCATION:		
Up to completed secondary	-0.175 (0.107)	-0.209 (0.211)
Higher	0.073 (0.435)	-20.291*** (1.151)
RESP. WEALTH:		
Poorer	-0.046 (0.110)	-0.072 (0.173)
Middle	-0.017 (0.098)	-0.043 (0.154)
Richer	-0.173* (0.103)	0.055 (0.184)
Richest	-0.287* (0.153)	-0.137 (0.222)
PARTNER EDUC.:		
Up to completed secondary	-0.137* (0.083)	0.220 (0.177)
Higher	0.031 (0.437)	1.394* (0.797)
HH HEAD AGE RANGE:		
31-45 y	-0.048 (0.086)	0.223 (0.170)
46-60 y	-0.071 (0.112)	0.404** (0.196)
61-75 y	0.104 (0.152)	0.339 (0.259)
RELATION TO HH HEAD:		
Head	0.243 (0.318)	0.325 (0.766)
Wife	0.308 (0.237)	-0.045 (0.352)
Daughter	0.392 (0.361)	-0.021 (0.437)
Daughter-in-law	0.383 (0.287)	-0.687 (0.474)
Granddaughter		-20.734*** (0.994)
Mother		1.491*** (0.507)
Mother-in-law	0.443 (0.354)	
Sister	-0.322 (0.452)	0.344 (0.605)
Not related	0.109 (0.310)	-0.593 (0.857)
RESP. WATCHES TV:		
Less than once a week	0.181* (0.103)	-0.116 (0.242)
At least once a week	0.227* (0.117)	-0.036 (0.224)
Almost every day		0.027 (0.329)
RESP. VISITED H. FACILITY:		
Yes	0.025 (0.085)	0.025 (0.102)

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PROMPT ANTIMALARIAL UPTAKE - KR (cont.)	2010	2014
LITERACY:		
Able to read only parts of sentence	0.233* (0.129)	0.450* (0.266)
Able to read whole sentence	0.110 (0.153)	0.008 (0.352)
DISTANCE TO H. FACILITY:		
Not a big problem	-0.080 (0.070)	-0.202* (0.104)
COST TO REACH H. FACILITY:		
Not a big problem	-0.254*** (0.082)	0.168 (0.131)
RESPONSIBLE FOR HEALTH EXPENSES:		
Respondent and husband/partner	-0.064 (0.130)	0.652** (0.321)
Respondent and other person		0.918 (0.863)
Husband/partner alone	-0.104 (0.111)	0.271 (0.281)
Someone else	0.563** (0.256)	0.062 (0.429)
Other	-0.502 (0.402)	
RESPONSIBLE FOR LARGE EXPENSES:		
Respondent and husband/partner	0.301* (0.178)	0.275 (0.206)
Respondent and other person		-0.964 (1.450)
Husband/partner alone	0.075 (0.166)	0.255 (0.221)
Someone else	-1.047* (0.566)	0.821** (0.358)
Other	0.984*** (0.277)	
N	939.000	1577.000

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 17: Determinants influencing a prompt uptake of antimalarial medications for the treatment of fever in children for 2010 and 2014 in Burkina Faso.

For base levels please review Table 3 to Table 8. The statistical analysis takes in account the sampling strata and units. The standard errors are clustered at household level.

Once the determinants of the uptake of antimalarial medications had been identified it was crucial to understand whether there were differences that also led to a prompt uptake of the same technology.

As Table 17 shows, this analysis did not yield sensible results, leading to the conclusion that other factors may be at play in the uptake of uptake of antimalarial medications for the treatment of fever in children in Burkina Faso.

8.3 Discussion

The econometric analysis of factors affecting the ownership and uptake of various malaria elimination interventions in Burkina Faso support findings from the general research literature on adoption and diffusion of health innovations (see Chapter 2), as well as the key factors found in the systematic literature review on the uptake of malaria eradication technologies more generally (see Chapter 5). To summarise, the following were identified as significant:

Geographic factors:

- Discrepancies between rural and urban cohorts (area of residence) in the availability and consequent uptake of certain innovations.

Socio-demographic and cultural factors:

- Age of both respondents and household heads;
- Use of radio and TV to transmit specific health messages to the population;
- Ability of women to take leadership over decisions on health and large family expenses;
- Gender imbalances, such as the women's necessity to need permission from partner or household head to go for a treatment or having to request money for it;
- Education level of both respondents and household heads.

Household factors:

- Size of household;
- The total number of people living in the same household;
- Household ownership of television and radio as well as their use by family members.

Economic factors:

- Household wealth index.

Variables related to use of healthcare:

- Geographical distance to primary health facilities and ability to reach them;
- Primary source of health information, in particular CHWs and health facilities;
- Visits of women and children to primary health facilities and in particular the attendance of women to antenatal visits;
- Quality of technology available on the ground.

Significantly, this study identified the importance of culturally specific determinants, in particular the importance of both the family relationships and wider social relationships. These seemed very predominant in the Burkinabé context, while they have not been particularly emphasised in the existing body of research. As explained in Chapter 7 the Burkinabé society assigns extremely high value to hierarchical structure, with many informal leaders and rules, both within society in general as well as within households. This factor seemed to clearly impact on the use and uptake of certain interventions. This was clearly demonstrated by the variables ‘relationship of the respondent to the household head’ and ‘number of additional wives’. For example, in the case of IPTp, second wives were 6.6% less likely to take IPTp compared to the first wife. Furthermore, this phenomenon was recurrent throughout the years of the surveys (ranging from 2003 to 2014), thus indicating that it is deeply rooted in the Burkinabé culture and way of living.

Having considered the factors influencing the adoption of previous interventions to control malaria, the next step within this PhD study was to look in detail at the introduction of a very innovative intervention at different levels within the Burkinabé health system: genetically modified mosquitoes. The author anticipated that some of the factors identified in the analysis of the DHS data would be influential in this case as well. However, it is important to reiterate that the type of

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malaria technologies investigated in the econometric analysis in this chapter involve *individual uptake* of interventions, by households, men, women, and children. In contrast, the adoption of GM mosquitoes, as a public good, does not entail an individual decision, but rather a *societal and governmental* one. Furthermore, the econometric analysis in this chapter focused on relatively simple and well-understood private goods technologies for malaria elimination (e.g. bednets), while GM mosquitoes are not only a highly complex technology, with an extremely intricate product development pipeline, but one that is also hard to understand and explain unlike a bednet.

Hence it is important to understand how individual-level decisions interact with governmental-level decisions, and are reflected within the adoption process for GM mosquito technology.

9 Development and adoption of a GM mosquito technology: Target Malaria in Burkina Faso

9.1 Methodology

9.1.1 Qualitative system dynamics modelling

Building on the findings on analysis of complex health interventions and the broad framework chosen for the investigation of the research questions (see Chapter 4.4.4), the author decided to adopt a mixed analytical strategy based on systems thinking (Atun, 2012, Atun et al., 2010a, Atun et al., 2010b) and qualitative system dynamics modelling (Sterman, 2000). These frameworks were used to analyse the data gathered throughout the PhD study, with a focus on the results of the coding of the interviews and focus groups. A full quantitative model was neither feasible nor practicable, given the non-quantifiable nature of the subject matter with all its inherent complexity and ambiguity.

System dynamics (SD) modelling was developed by Jay Forrester in the 1960s and has been established as an interdisciplinary method to enhance learning in complex systems (Sterman, 2000). It was established as a method to understand and to act in congruence with the long-term best interests of a system as a whole, identify its leverage points, and avoid policy resistance (Sterman, 2000). It was initially applied to industrial dynamics (Forrester, 1961) and was grounded in the theory of non-linear dynamics and feedback control. Hence, its central principle postulates that the structure of a system and the manner in which its components are interconnected and influence each other determines its behaviour over time. It is important to note that a system dynamics model should be developed to answer a specific research question, rather than to model the system (Sterman, 2000). This allows the exclusion of factors that are not relevant to the problem, in order to ensure that only key components are kept in the boundaries and the model remains manageable.

Despite the fact that system dynamics modelling is still gaining traction among decision makers within the public health domain, who frequently consider these types of models too convoluted and complicated to understand, it has proven

particularly effective in the design of more efficient policies and organisations over the past decades (Sterman, 2000). It has been applied in a number of fields to explain the dynamics of complex aggregate strategic level processes. These include, amongst others, public health and prevention programmes (Homer and Hirsch, 2006, Homer, 1993, Evenden et al., 2005), epidemiology of diseases (Roberts and Dangerfield, 1990, Jones et al., 2006), as well as community and social care (Wolstenholme, 1993, Bayer et al., 2007, Homer et al., 2004).

Nevertheless, given the complexity of the systems and the multitude of variables of a different nature taken into consideration, it is not always possible to quantify and hence model and simulate these complex systems. Some modellers claim that qualitative modelling is incomplete, but in 1999, Eric Wolstenholme praised the wise uses of qualitative mapping and laid out the conditions that actually require formal quantitative modelling within system dynamics (Wolstenholme, 1999). Over the years, it has become increasingly clear that despite the repeated affirmations that system dynamics requires formal, quantitative models for understanding the dynamics of complex systems, the need for quantification is relative and depends on the purpose of analysis (Wolstenholme, 1999, Wolstenholme E. F., 1985). Wolstenholme deemed both qualitative and quantitative system dynamics as equally important with their relative strengths and weaknesses and the choice should be mainly related to the purpose of analysis and the respective tool sets (Wolstenholme, 1999, Wolstenholme E. F., 1985).

In fact, qualitative system dynamics modelling can use both, causal loop diagrams as well as models based on stock and flows (the building blocks of quantitative system dynamics modelling) without computer simulations, to assist issue structuring and problem solving (Wolstenholme and Coyle, 1983, Wolstenholme E. F., 1985, Eden et al., 1979). These processes can result in either cognitive mapping (Eden, 1989) or systems thinking (Senge, 1990). The latter aims to provide insights into managerial issues by inferring the behaviour and dynamics of the system represented, rather than calculating them (Wolstenholme, 1999, Senge, 1990). Despite criticism, qualitative system dynamics modelling has shown that, even in this mode, its models are sufficiently rigorous to provide added value to the

structuring of issues and assessment of behaviour (Wolstenholme, 1999). Moreover, it is widely accepted that systems thinking can be of significant assistance to policy development in complex areas, compared with other diagrammatic tools like soft systems methodology (Wolstenholme, 1999, Checkland, 1981).

Within the scope of this PhD thesis, systems thinking was used to expand the boundaries of the mental models and to develop a qualitative system dynamics model. The principle goal of the model was to understand the behaviour of the complex system analysed (Stermann, 2000), and thus to understand key factors and behaviours leading to the adoption and development of Target Malaria's technology in Burkina Faso.

9.1.2 Data analysis

The main source of information used to build the qualitative system dynamics model was the ensemble of the transcribed formal interviews. This data was analysed in two main stages following the analytical path proposed by Azoulay et al. (2010).

During the first phase the author started exploring the theoretical constructs derived from the holistic framework described in Chapter 4.4.4 (Atun, 2012, Atun et al., 2010a, Atun et al., 2010b), used for the analysis of the case study as well as for the development of the topic guide and the semi-structured interviews. These constructs were:

- Problem perception;
- Knowledge and attitudes towards innovation;
- Structure and nature of the adoption system;
- Structure and decision making process of the health system;
- Dynamics and characteristics of the broad context;
- Knowledge and attitudes on GM mosquitoes.

The raw interview data was initially categorised and structured according to these theoretical constructs, in other words the author searched for relevant extracts from the interviews which related to the constructs. Once this had been done, the data associated with each of these nodes were then deconstructed into second- and third-order nodes highlighting the themes emerging from the interviews. This work was performed in Nvivo 10. During this stage, it was considered crucial for the author to maintain an inductive stance to identify important themes emerging from the data in order not be dragged into pre-existing mental model. The emerging themes were discussed with the research supervisors in order to reach a consensus on their meaning. Figure 28 shows that first and second order nodes.

In the second phase, qualitative system dynamics modelling – and more specifically the causal loop diagram method (Azoulay et al., 2010, Sterman, 2000) – was used to analyse the relationships within those emerging themes and to generate an explanation of the multilevel dynamics found within the complex system. This allowed the author to better understand the causal relationships and hence the underlying drivers of the intrinsic dynamics over time.

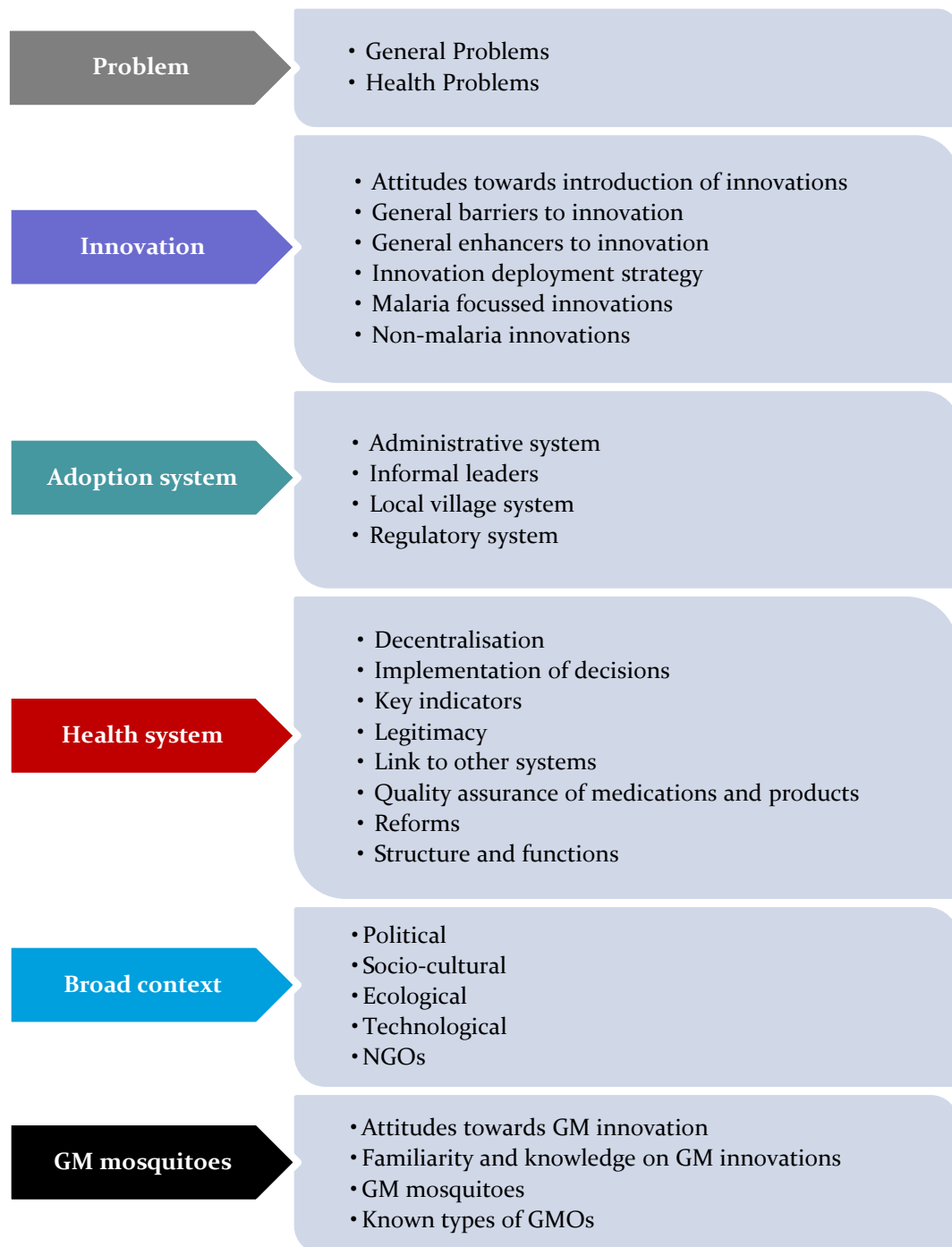


Figure 28: First and second order nodes from arising from the analysis of the interviews and focus groups in Burkina Faso.

Creation of a qualitative system dynamics model

To build the causal loop diagrams, which then evolved into a qualitative system dynamics model, the author adopted the following approach. This represents a modified version of the process suggested by John Sterman (Sterman, 2000) to account for the fact that the planned system dynamics model was a qualitative and not a quantitative one:

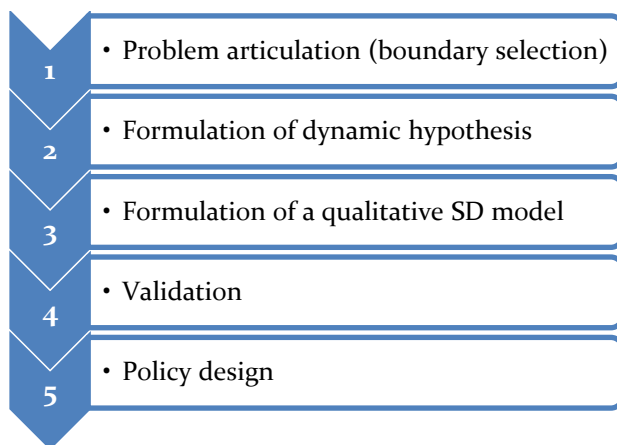


Figure 29: Steps of the qualitative SD modelling process.

The first step, problem articulation, was characterised by the clarification of the theme which was defined as the analysis of the key factors for the development and adoption of GM mosquitoes in Burkina Faso, and also the current phase of development of the technology in relation to the overall project timeline. In this first step the first preliminary key variables were identified based on the concepts arising from nodes established in the first phase of the data analysis in Nvivo (Section 9.1.2).

The next step involved the development of explanations for the system's dynamics in relation to the endogenous and exogenous consequences of its feedback structure. This process was based on the findings from the interviews and focus groups as well as on the other analysed data gathered throughout the PhD. It entailed the development of maps of causal structures based on the initial hypothesis and variables. The causal loop diagram was developed from those. The former explains

the causal influences among variables by connecting them with arrows and detecting the resulting feedback loops (Sterman, 2000). It is a crucial process, since causal loop diagrams elicit and capture mental models and hypotheses about the system's behaviour (Sterman, 2000, Morecroft).

The third step involved the introduction of stocks and flows within the model (Sterman, 2000). Stock and flows track accumulations of materials or information as they move through a system. Stocks are accumulations of the material or information (e.g. populations rates or inventories of a product) representing the difference between the rates of increase or decrease in stocks, also known as inflows and outflows (Sterman, 2000). These flows characterise the state of the system by giving it inertia and providing it with memory (Sterman, 2000). This is due to the fact that differences in the rates of in- and out-flow create delays and are the source of disequilibrium dynamics in the system (Sterman, 2000).

Stocks and flows, as well as feedback loops, constitute the key pillars of system dynamics modelling and were used as the basis for the formulation of a structured qualitative system dynamics model (Sterman, 2000). Throughout the development of the model, the author ensured that its boundaries and the level of details within it were kept in balance. This factor was crucial to create a useful, operational representation of the factors and levers available, while capturing all the needed feedbacks, especially those unaccounted for in the mental models of the stakeholders and author.

Modelling often works best as an iterative process between modeller and stakeholders involved in the modelling process (Sterman, 2000). Unfortunately this was not possible due to the type of participants in the study. Nevertheless, validation of the model was a continuous process undertaken by the author in order to build confidence in the model and challenge its assumptions. In order to accomplish this, constant reviews of the emerging model were conducted both with the supervisors as well as with three independent reviewers with expertise in system dynamics modelling applied to complex innovation processes. Those reviewers were: Dr Steffen Bayer (University of Southampton), Assistant Prof Brice Dattée

(EMLYON Business School) and Dr Mohamed Lebcir (Hertfordshire Business School).

Furthermore, given the limited previous exposure to SD modelling, the author also attended a system dynamics course at the MIT Sloan School of Management (Cambridge, MA) over the winter semester 2015/16 in order to gain first-hand experience in modelling complex systems before starting the modelling process for this PhD study.

Once the qualitative system dynamics model was finalised, it was used to design and propose new robust policy recommendations on the next development steps for Target Malaria's technology (see Chapter 10). These included the review of some of the existing policies, as well as the conceptualisation of entirely new strategies. Given that the feedback structure of a system determines its dynamics, when developing strategic or policy recommendations it is crucial to explore and create actions which are able to influence the dominant feedback loops (Sterman, 2000).

9.2 Results

9.2.1 Overview model

Figure 30 provides a high level overview of the qualitative system dynamics model describing the interaction between key factors influencing the introduction of GM mosquitoes into Burkina Faso.

During the elicitation process it became apparent that there are two levels influencing the adoption of the technology on the ground, driven by the nature of the technology in question as well as its product development and adoption process: on the one hand the policy and regulatory level and on the other hand the general population level. Both interact and influence each other. The most important dynamics between and within these two levels are represented in the overview model, while the detailed model describes different components of those two levels more comprehensively.

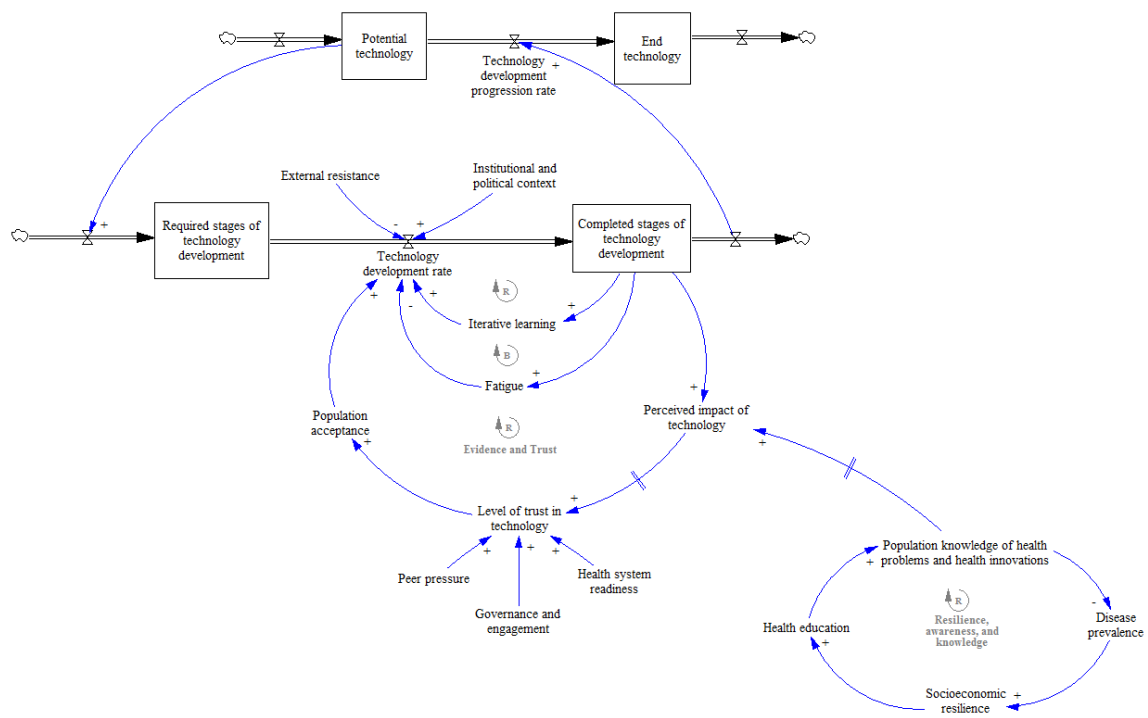


Figure 30: Overview model of the detailed SD model for the adoption of GM mosquitoes in Burkina Faso for the eradication of malaria.

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The stock and flow box at the top of the model describes the new product development (NPD) process for GM mosquitoes in terms of progress from the original idea of a *potential* technology towards a *fully developed* self-sustaining mosquito strain with a proven effect on malaria elimination in Burkina Faso.

The transition from potential technology to the final technology is further subdivided in a second stock and flow element. This process comprises the three phases of technology development (self-limiting sterile male, self-limiting male bias, and self-sustaining male bias or fertility gene knock out), as well as the various testing stages for each phase as detailed in Section 6.1.4. These also include all the necessary regulatory approvals which are considered milestones towards both, the development of the final technology as well as the adoption of the technology in Burkina Faso. This interim process is represented by the product development progression rate and is an iterative process until the final technology is reached.

The interview process revealed several exogenous and endogenous factors at policy and regulatory level with a significant impact on the product development rate. The exogenous factors can be clustered in two groups: external resistance factors and the readiness of the institutional and political context to adopt the technology. The endogenous factors result from the completion of the various technology development stages and can be clustered into factors leading to reinforcing iterative learning loops as well as factors creating balancing ‘fatigue’-generating loops (described below).

All these factors influence the speed at which the GM mosquito technology moves from being a *potential* innovation to becoming an *actual* innovation deployed in the field at policy and regulatory level. However, besides these factors, as mentioned above, there are also a number of further factors, like the important interdependencies with the population level.

In fact, given the peculiar product development process, each completed technology development stage also influences the perception of the impact of the technology on the ground by individuals within the population. This perception is, in turn, affected by the broader context especially by knowledge of health problems and health innovation across the population. This perception, together with the health

system readiness, the societal peer pressure, and the governance and engagement of the technology on the ground influence the level of trust that individuals have in the technology. Given that GM mosquitoes are not adopted on an *individual* level, the level of trust – unlike in most adoption models – does not lead to an *individual* uptake of the technology, but there may nevertheless be support or rejection of the technology by individual. The balance between the *convinced* and *unconvinced* population therefore shapes the general level of population acceptance towards the technology. Consecutively, population acceptance has a strong impact on the product development rate, closing the loop between the population and the regulatory and policy levels. In fact, population acceptance was deemed to be the factor with the highest level of influence on the product development rate, not only by the regulatory experts, but also by many national interviewees at decision making level, creating an extremely powerful link between the two levels.

The sum of these dynamics between the key factors influences the adoption of the technology on the ground. It is important to note that some of these dynamics include time lags due to knowledge transfer gaps. These can lead to oscillations of the model and are represented by the following symbol: H in the model diagrams.

The following sections of this chapter provide a comprehensive description of the various segments of the detailed quantitative system dynamics model. It is important to fully understand all the complex dynamics underlying the adoption of GM mosquitoes in Burkina Faso in order to effectively deploy appropriate deployment strategies and policies and to understand short and long term consequences.

9.2.2 Population acceptance and understanding

The holistic framework outlined in Section 4.4.4 (Atun, 2012, Atun et al., 2010a, Atun et al., 2010b) has given the author pointers for the analysis of adoption and diffusion of innovations in health systems. Amongst other factors, this stresses the importance of the problem perception by stakeholders – including end-users, patients or the local population – and the context for adoption. This component of

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the model largely influences the scale and speed of the adoption and diffusion of the technology within the system, hence the author decided to start building the model based on these factors.

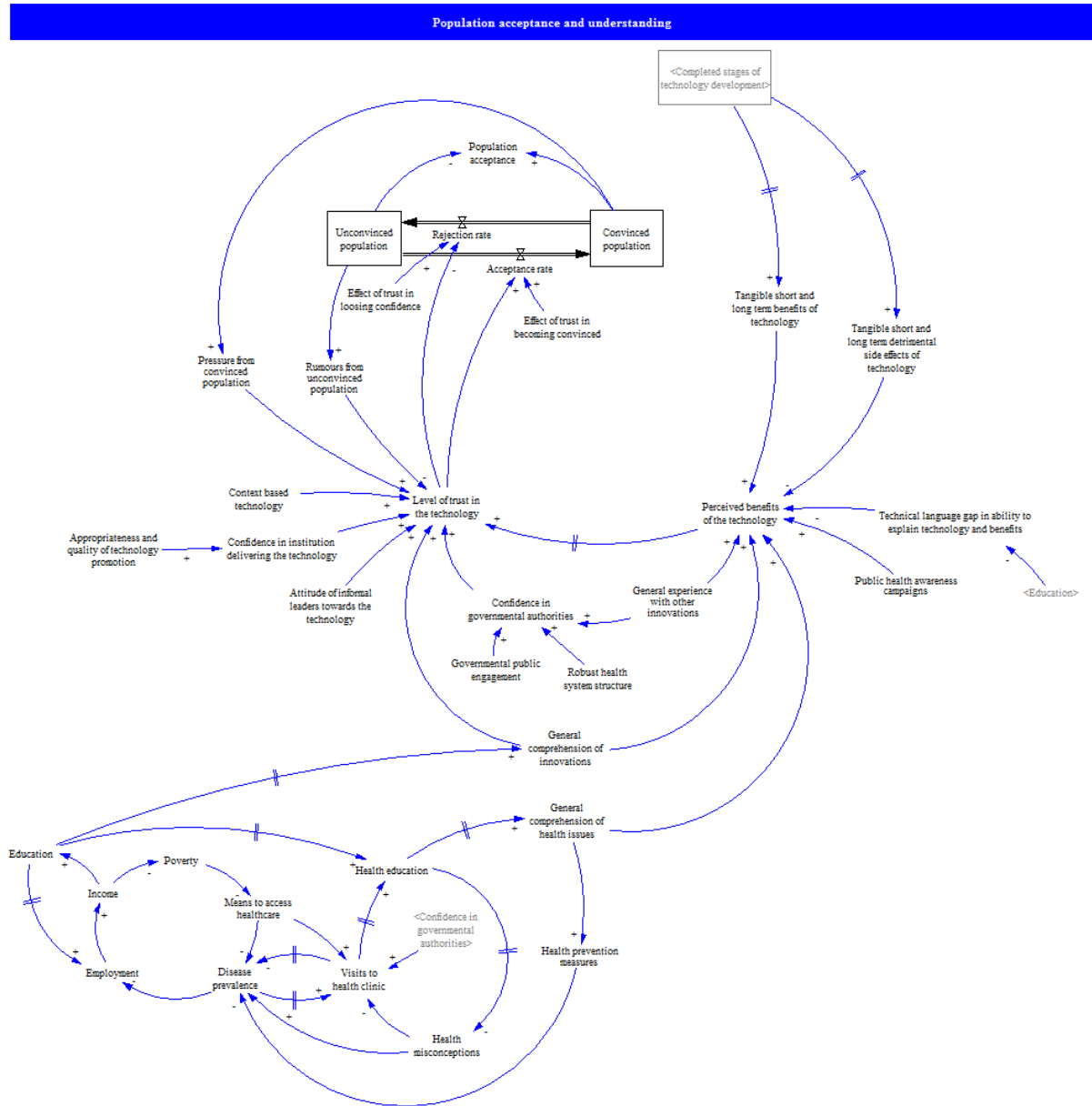


Figure 31: Population acceptance and understanding level of the detailed qualitative SD model for the analysis of the adoption of GM mosquitoes in Burkina Faso for the eradication of malaria.

Resilience, awareness and knowledge loops

The interview and documentary material suggested that an extremely important component of population acceptance and understanding were the general comprehension of health issues and general comprehension of innovation as defined in Section 2.1.3. These were themselves influenced by a set of socio-economics variables relating to education, employment and use of the current health system. This is described in the model below.

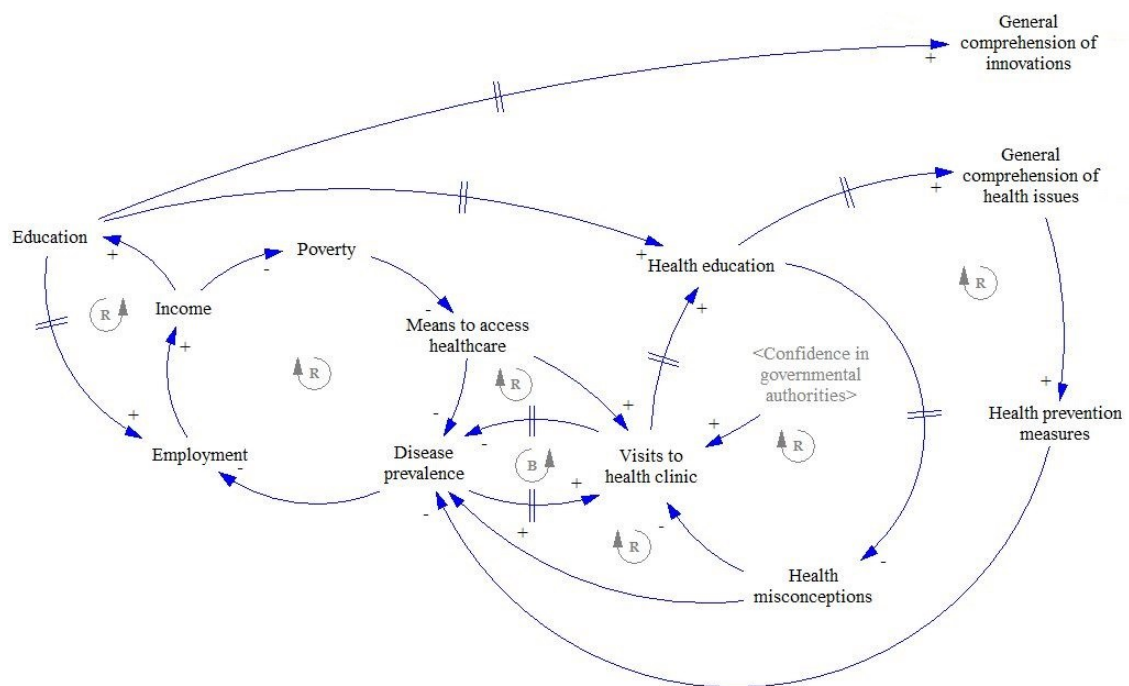


Figure 32: Overview of the resilience, awareness and knowledge loops of the detailed qualitative SD model for the analysis of the adoption of GM mosquitoes in Burkina Faso for the eradication of malaria.

Poverty, employment and education emerged from the interviews and focus groups as the three major issues experienced by the local population. These were mentioned respectively by 12 informants (16 references to poverty issues), 13 informants (15 references to employment issues), and 12 informants (16 references to education issues). The relationship between these three variables impacted on monetary or geographic means to access healthcare, which was also considered as the major health issues by interviewees at a local level (monetary or geographic factors were mentioned by 10 sources, respectively 21 and 15 times).

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The selection of quotes from the interviews illustrates these population concerns or perspectives (for the full set of key quotes, incl. the original verbatim, see Appendix 12.6):

“There is also the problem of enrolling children to school. This becomes more and more expensive. Most little ones stop at middle school level due to lack of funds.” Retired health professional

“But above all, the essential, the biggest issue: poverty [...]. As far as the Imam is concerned, people are seeing him because of a range of problems with poverty being the biggest issue. Out of 10 people, 8 are coming because of poverty.” Religious leader from a rural village

“Globally speaking, poverty is the most visible and clear factor, which is further accentuated by low enrolment rates. And so the poverty cycle is increasing.” General Secretary of a network of NGO

“Sore feet, hypertension, diarrhoea, stomach ulcers... the fact of not being able to work.” Member of an all-women focus group from a rural village

“The third big problem here is labour, the production activity.” Religious leader from a rural village

“There is a problem of poverty and a problem of assertiveness. Even if you have ideas you do not have the chance to pursue them. It would be encouraged by the educational system but depending on the provinces, in the Center-North for example, people don't go to school. And even if they go, it's for boys only; girls don't go to school, there are even villages which have decreed that girls must not go to school. And if they go after all, they come back pregnant from the 5th or 4th grade onwards. Thus, it is preferred to keep them at home, to wed them within the village and not send them to school.” General Secretary of a network of NGOs

“The basic problems, the priority needs are education, healthcare, sanitation, road infrastructure. Those are the main problems: health, education, roads...there you go.” General Secretary of a governmental administration

Through discussion, these data were constructed into the reinforcing loop on ‘resilience’: lack of employment leads to lack of income and hence an increased poverty of the population. This, in turn, reduces the means to access healthcare (both monetary and geographic) and consequently has an impact on the disease prevalence. An increase in disease levels and the subsequent drop in employment levels close the reinforcing loop, as shown in Figure 32.

This distressed situation found on the ground is strengthened by the fact that reduced income has an adverse impact on education, which also has a reinforcing negative effect on employment.

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“Especially in the rural environment, it will be [issues like] the poverty of the population, the lack of information, illiteracy which will create problems; those are linked to a great extend to comprehension. Grosso modo, it's the illiteracy... people are not informed. The people do not know or don't understand what is proposed to them. In the healthcare sector, the problem is the same.” Retired mayor of a mid-sized village

“There are a lot of problems: poverty, access to basic social services, healthcare, education, employment for young people and women. Problems are also production output - if you go to rural areas - and difficult access to borrowing, agricultural loans as well as to support to be able to develop their livelihood and manage their revenues in order to confront their needs.” Project manager of a national NGO

Disease prevalence and a low attendance to primary health facilities were also highlighted as problems, but principally by health professionals with managerial roles within the health system and with a good understanding of the country's health statistics. In fact, it became clear that the less the means to access healthcare, the less people have the possibility to travel to primary health facilities for any type of visit (curative or preventive). This in turn potentially leads to increased disease prevalence on the ground. On the other hand, the greater the disease prevalence, the more people are encouraged to use primary health facilities. This has a balancing effect on disease prevalence. However, these dynamics are not straightforward, and there are time delays and hence oscillations within the system.

“The health policy document has identified the main healthcare problems in Burkina Faso which resulted from the high maternal and infant mortality. [...] And the most addressed diseases are malaria, tuberculosis, HIV and the promotion of reproductive health.” Executive director within the Ministry of Health

“Health is a priority issue for our populations. But if we say health it is important to understand what is subsumed under health. According to the WHO, this is based on a state of complete well-being; not on the absence of disease but the physical, moral and material well-being. So if we say that health is the main problem we need to look at this in a general way.” Representative of a civil society group

“There is no impetus to visit a healthcare facility if one is ill because one expects costs that could not be covered. The impetus would be to manage one's illness as good as possible which will lead to a significant delay before visiting the healthcare facilities. When the people get there it is already too late. Everything is a problem here.” Communication officer of a national NGO

“[...] we have always had problems because people arrive [at the facilities] but too late which means a lot of [prior] self-medication or consultations with a traditional healer.” Regional director within the Ministry of Health

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At a local level, the way the problem (prevalence of malaria) was currently perceived was also found to be an important determinant of attitudes towards the health system and health issues. The fact that the major health problems mentioned were the result of a lack of financial and geographical access to primary health facilities, rather than certain types of diseases showed a clear mistrust and disillusionment with the health system, as well as an extremely low confidence in governmental authorities in relations to health matters. This leads to a further reduction of the visits to health clinics.

“Access to healthcare services [is one of the big challenges], not only concerning the physical access but also with regards to healthcare costs as there are no social insurance health insurance schemes to cover those costs; thus, may prefer to remain on the sidelines.” Member of civil society association

“Similarly, problems are linked to management capacities of the health system, its coverage, quality and financial accessibility of healthcare services for the population.” Executive director within the Ministry of Health

“For example, it is possible to have geographical access to healthcare centres but a number of people living in the proximity of those centres won't go there; there are people with financial access but they won't go and are reluctant. It is mainly a cultural problem; the way of communicating plays a big role. So people can be within acceptable distances but won't go there.” Representative of a civil society group

“She added that some say that if doctors flattered them to get vaccinated, that shows it's because they want to inject diseases in their bodies so that they go and pay more money at the CSPS. The doctors would get them ill so that they would go to the CSPS and pay a lot of money there. That is the idea of some of them.” Member of an all-women focus group from a rural village

“If someone comes and ask to vaccinate them, and they had never heard about it, they would refuse it because they wouldn't know what the person would be injecting in their body. They would even hide their children...” Member of an all-women focus group from a rural village

“The problem we have today with the implementation of the measures is the leadership at the central level. The power of the central level is very low; the DRS and MCD think they can do what they want regardless of the decisions of the central level. And they do so without sanctions. Unfortunately, there is virtually no sense of accountability.” Founder and leader of national NGO

This lack of confidence in both the health system and governmental authorities was mainly due to the wider political instability of Burkina Faso and its consequent lack of governance and low economic performance (see Chapter 7). This impacted on the confidence of the population in local formal and leaders rather than local

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authorities. In fact, as explained in Section 7.2.1, within the Burkinabé society local leaders – including the chief of the village, the elders, religious leaders, and the members of the CVD (Conseil Villageois de Développement) - play a crucial role in the daily life and are far more influential than governmental authorities. Additionally, whenever the local leaders take a very conservative approach and reinforce local traditions, this might enhance the misunderstanding of certain diseases.

“We involve the local leaders: village chiefs, deputies, envoys, the CVD of the village, as well as the 'leader of tradition'. So people come because they participate. We need their technical help. The people say: 'there are the traditional leaders'... and then they come.” Retired mayor of a mid-sized village

“In every village, there are the leaders of the communities, Muslim or Catholic, who participate in the communication of techniques (Ministry of Health).” Retired health professional

“The village chief has his advisors, his confidantes with whom he discusses and gives information to the population. He summons the family council and shares information. Generally, he will not be much challenged. He decides. No, no the chief will not be challenged.” Retired health professional

“The village is organised based on groups and cooperatives. Essentially, there are three people with power: firstly, the CVD, then the Jeunesse - a group of young people - has a say and the Imam [...] also has an incontestable power in the village.” Chair of CVD of a rural village

“When there is a piece of information to pass to the people, when the man gets the info, he goes to the leader: the chef de village, le conseiller et le cathecist. The chef de village and le conseiller will dispatch the piece of news to the village and in the meanwhile, the imam inform the people in the mosque and the cathecist inform the people to the churches. When there is a piece of information to transmit, that's easy.” Religious leader from a rural village

“We have the community health workers [and] we have the correspondents in the village. Besides this, all innovations in the health sector involve the 'leaders of tradition', religious leaders, village chiefs and land chiefs; they pass on the information because people listen to them. The Imam and the 'leader of tradition' will transmit [the messages]. Our correspondents in the villages help us to pass on the information concerning innovation that must be introduced in the health sector.” Health professional in a regional CMA

It was clear from the interviews and focus groups that the Burkinabé population has a low understanding of health issues and does not perceive malaria as a problem. There are two main reasons. Firstly, due to fact that malaria is so widespread and common, it is perceived as a common, mostly irrelevant and curable disease, and it is considered to be of minor importance by the population. Secondly, despite all the

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efforts and public campaigns undertaken to improve public understanding of vector-borne diseases and in particular malaria, there are still a large number of misconceptions which are deeply rooted in the Burkinabé culture. Especially in rural areas, the excessive consumption of different sorts of fatty or sweet foods (e.g. mangoes, milk, sweets, old oil), the direct exposure to the sun, lack of sleep, exhaustion due to excessive labour, and contact with rainfall are believed to also transmit malaria. Furthermore, one of the biggest issue is that in a lot of cases that the majority of malaria symptoms besides fever are often attributed to other illnesses which are usually thought to be caused by evil spirits or supernatural causes and only rarely by natural causes or diseases. This holds especially true when the high fever leads to hallucinations or convulsions. As a result, malaria treatment is often not sought or only with major delays (as described in Chapter 6).

“In terms of malaria, the population perceives this almost as a normal disease which is regrettable. All the protective measures that we are implementing are still not always being followed.” Executive manager within the Ministry of Health

“Malaria is seen as an every day’s disease, everybody has malaria. It’s a normal disease for everyone.” Project Manager within the Ministry of Health

“Traditionally, when someone had malaria, they don’t care very much, if it didn’t pass they go to the traditional doctor.” Religious leader from a rural village

“Malaria is a frequent and recurring disease that is easily curable - even without treatment - for people carrying Plasmodium, the malaria germ. [...] There are assessment errors; people do not realise that the disease can also be serious and deadly.” Manager in a regional CMA

“When one has malaria, the skin swells; one looks tired. Looking at the face one notices that it’s malaria.” Member of an all-women focus group from a rural village

“The populations perceive [malaria] as a common disease. With regards to mortality, the do not necessarily make the connection with malaria, except maybe with fetishes or sorcerers; that’s the most.” Executive director within the Ministry of Health

“Generally in our cultures, if somebody is sick we always think that someone has cast a spell on you; that’s the case in African culture. [...] Generally, we go to the marabou or the witch doctor for a consultation rather than going straightaway to the dispensary or the hospital. [...] Particularly concerning diseases that strike the mind, malaria, or when children are cramping, like with tetanus or meningitis, this occurs brutally and has mortal consequences.” Socio-anthropologist on national level

“In the case of malaria, if a child has cramps we say that this is due to the bird - ‘it’s the bird, it’s the bird’ - and this conditions people not to think of malaria.” Retired mayor of a mid-sized village

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“Every time, there are associations that explain it. They say that the mosquito transmits malaria, every time. Up until now, the people still don't believe that. Some say that it is caused by eating mangos or fatty meals. The people don't understand that it is the mosquito that transmits malaria - they don't understand.” Chief of a rural village

“The traditional treatment they do usually lasts for one day. If at the end of that day the illness has not responded, they can go to the healthcare centre.” Member of an all-women focus group from a rural village

This was perceived differently by health professionals at managerial and policy maker level, stressing even more the geographical gap and cognitive distance between the health system and the population.

“It all depends on the first reason for consultation and in Burkina Faso that is malaria. [...] If you read the annual statistics, the first reason is malaria.” Manager within the drug allocation department of the Ministry of Health

“In most healthcare documents, malaria is listed as the leading cause of death in Burkina Faso.” Project Manager within the Ministry of Health

“We have the same epidemiological profile as in other regions; above all malaria which is a public health concern.” Regional director within the Ministry of Health

“Currently there are plenty of diseases, especially malaria, typhoid fever and currently also sinusitis.” Representative of a civil society group

This gap was recognised by policy makers and, in order to reduce it, a series of policies were set in place through the programme for the national health system development, the PNDS (see Section 7.2.2), in order to enhance health education. This was done at two levels: (1) health system professionals are not only supposed to provide care during visit but also communicate with patients and teach them on health issues in order to improve their health education; (2) introduction of health education in primary and secondary school programmes. Hence, the model introduced the fact that both education and visits to health clinics are a crucial reinforcement for health education. Both of these dynamics, though, involve extreme time delays as the effects are obviously not immediate, leading to further oscillations of the system. In turn, over time health education was deemed to lead, with delays, to a better general comprehension of health issues and hence to increased health prevention measures, resulting in a reduction in the overall disease prevalence on the ground. Moreover, improved health education levels have a strong

impact on the health misconceptions rooted in people's beliefs, leading also to both a reduction in the disease prevalence and a surge in visits to primary health facilities. The time lags here are caused by the difficulty in changing deeply-rooted habits of the population. These dynamics result in a series of reinforcing loops as shown in Figure 32.

"The key factor is communication. Communication is essential so that new technologies are correctly used by the population. We need to focus on communication, information and awareness." Communication officer within the Ministry of Health

"They [the population] have habits that they are asked to change and they have difficulties adopting new behaviours. This is the level of understanding and the well-founded behaviour that is said to block it. If they don't understand this they will be reluctant. It's the level of understanding that leads to reluctance." Health professional in a regional CMA

"There is also the fact that in the communities, men are often reluctant to respond to certain interventions." Interim consultant for Ministry of Health

"These diseases last for some days, or also a month or two months, some months, the Burkinabé consider them as unnatural or sometimes like a spell. Thus, [the people] invest in supernatural measures before realising that it would be enough to simply follow the health advice so that it doesn't get worse or settle in completely. This problem is part of the battle linked to the information in order to change the mind-set." Public Health professional within the PNL

The general gap between knowledge of epidemiology, science and technology prevalent in developed health systems, and the perception of the Burkinabé population seems to make it harder for the two worlds to interact and create a conversation. It became evident from the interviews that despite the obvious time delays that are implicit in this dynamic, an increased level of education also leads to a better general comprehension of innovations and of the basic knowledge that lies behind them.

These findings from the interviews and focus groups about the problem perception and the propensity to use the formal health system reinforce previous research on healthcare use in African countries. In particular, they demonstrate the importance of health system infrastructure on the ability of the population to gain access to primary care, a recurring barrier to the adoption of certain health related innovations highlighted in the prior research literature. As described in Chapter 7 over a third of the Burkinabé population lives over 10 km from the nearest primary

care facility (CSPS), making it almost impossible to reach, given the economic prosperity and ability to travel of the people. In certain areas, this is even more increased due to a geographic disparity in the distribution of CSPS on the ground. Hence the author found geographic factors were important in our case study, however poverty, employment and education were considered as more significant factors influencing the adoption of a new technology.

Together, all these factors and the dynamics between them led to the creation of the resilience, awareness and knowledge loops, with population knowledge of health problems and health innovations being the two main interlinking variables. These in turn influence to the evidence and trust loop, described next.

Evidence and trust loops

The resilience, awareness and knowledge loops explained how the problem perception, along with certain contextual factors, influence disease prevalence and use of the primary health system, as well as how they impact on the general comprehension of both health issues and innovations. The data from the interviews and focus groups further suggested that these two key variables have a major impact on the perceived benefits of innovations as well as on the level of trust the population sets in these. These were found to be the two crucial factors leading to the general level of population uptake or acceptance of innovations in Burkina Faso.

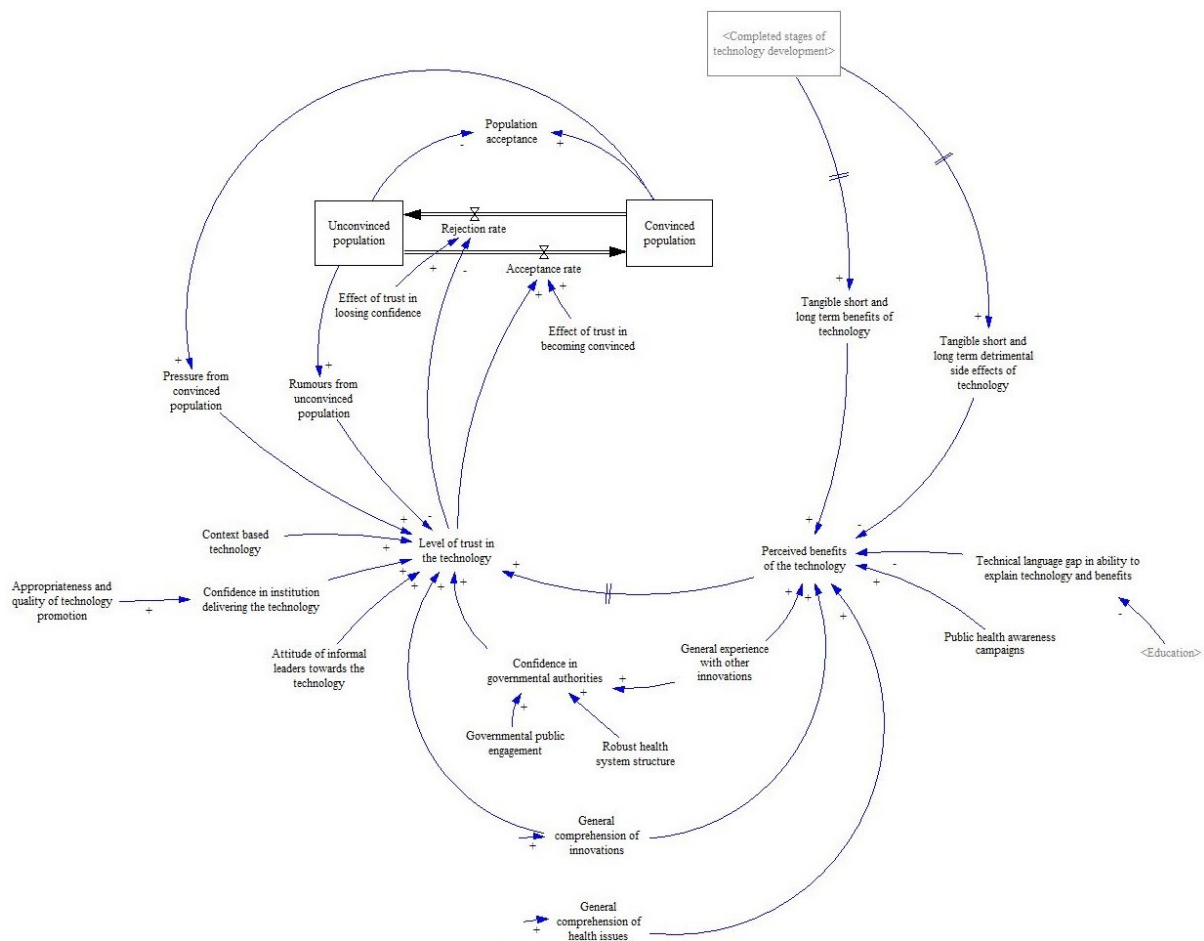


Figure 33: Overview of the evidence and trust loops of the detailed qualitative SD model for the analysis of the adoption of GM mosquitoes in Burkina Faso for the eradication of malaria.

The data suggested a strong relationship between general comprehension of health issues and people's perceptions of the benefits on health innovations and technologies. This was based on the facts expressed mainly by health professionals at the technical level (e.g. doctors in primary health facilities), who explained that once there is a comprehension of the health issues (i.e. malaria origins and transmission), then there is greater likelihood there will be better comprehension of the potential benefits of a specific technology, whether bednets or GM mosquitoes. This was reinforced by a better general comprehension on innovations as well.

"We try to sensitise them in order to make them understand. [...] Habit is a second nature. It needs time to drop the bad habits unless you have good intentions. But if this seems easy and if you are convinced of the positive contribution to your daily practice, it works." Manager within the drug allocation department of the Ministry of Health

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“The approach that is used today: we create awareness, we conduct focus groups - that's an innovation. [...] Because today we cannot eradicate the evil but we need to sensitise them, to organise them spatially, to give them treatment units. [...] The first step is to raise awareness to enable them to understand: understand what the upcoming problems and the immediate solutions are so that they are aware of the problem and asking the question of the solution.” Leading manager within a directorate of the Ministry of Environment

Comprehension of innovations as well as health issues were by far, though not the only, factors influencing the perception of benefits. From the interviews, it became clear quite quickly that the local culture and context tends to favour innovations that provide and immediate and tangible feedback rather than long term solutions. This was, for example, a major problem in previous vaccine campaigns, where the short term side effects of the vaccines (i.e. fever or numbness of the body part where the injection was given) played a crucial role in the rejection of the technology. These imminent effects were much more important and evident to the Burkinabé population than the long term immunisation effects, which became only visible during epidemics.

“People refused to get their children vaccinated because, for example, if the child get vaccinated, it may run fever and then, in that case, your work is disturbed all through the day. She also said that if your child get vaccinated it will die, and she has added that the new vaccines, particularly the one made on the side, is very painful and the day the child is vaccinated in that way, you are sure you won't be able to do anything else because he is so much elative, that you have to wait on him.” Member of an all-women focus group from a rural village

“How can't you get aware when you have your child ill and you refuse to get him vaccinated? Your neighbour gets his vaccinated, his got saved and yours is dying. In that case you know the advantage of vaccination.” Member of an all-women focus group from a rural village

“In the beginning it was difficult; the women did not to vaccinate their children. But one day, the measles attacked the neighbourhood and we knew that everyone who was not vaccinated got the measles ... afterwards, everyone got vaccinated. Now, all children are vaccinated.” Chief of a rural village

“When it's new people don't understand. They need to understand and generally any new activity that you introduce requires long preparations in order to sensitise the community; otherwise, your will find yourself lone and are bringing in an activity that does not work. For everything that is new you need to take the time to explain; it is necessary to start preparations early if you want to have an impact with the project. You need to be sure of this in the short- and mid-term.” Member of an international NGO

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The low confidence in governmental authorities also led to an attitude in the Burkinabé population that ‘we have to see it to believe it’ – in other words, the population often would not believe a government pronouncement until it actually delivers outcomes on the ground.

“Doctors would tell them that what they want, what they do, vaccination, is not something bad. They tell them the advantage. Some accept, some others refuse. In that case, if you have refused, and the disease comes and you see that your child get more attacked than other children, then you come to understand.” Member of an all-women focus group from a rural village

“When a population rebels against its prefect, there is a problem: the population does not trust its prefect. Otherwise, they would have communicated. Thus, the social distance was large.” Representative of a civil society group

Hence, any type of experience of the population with the specific technology being introduced – in particular the quality and timeliness of the benefits as well as the ease of understanding the evidence emerging from its deployment phase – was deemed to deeply influence people’s perceptions of short and long benefits or side-effects of that technology and played a crucial role in the path toward its acceptance.

“The people need to see the advantages of innovation, meaning that it is a reference. When there are innovations there are advantages.” Retired health professional

“Those who refuse it do it because they have not understood. And now that she has come back to the advantages, people have understood and travel until Nasso in order to get treatment.” Member of an all-women focus group from a rural village

Different technologies did not seem to be perceived in silos by the population. On the contrary, prior general experience with other innovations also played a major role in influencing acceptance. Positive prior experiences led to a greater openness towards the perception of benefits, whereas negative prior experiences led to the exact opposite as well as to a lower confidence in authorities. In addition, the nature and quality of people’s past interactions with government, NGOs and development projects delivering technological interventions locally was also central.

“If they have had a bad experience in one case, they will tell you by word to moth that [the innovation] will kill. This is an element that can constitute a hurdle towards acceptance of those innovations.” Manager in a regional CMA

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The data from the interviews suggested that the perception of benefits of innovations was also influenced by issues of comprehension, such as the ability of proponents to explain the technology and in non-technical language. This was also influenced in part by level of education present on the ground, creating another link between the resilience and the evidence and trust loops.

“Habit is a second nature. It needs time to drop the bad habits unless you have good intentions. But if this seems easy and if you are convinced of the positive contribution to your daily practice, it works. But if it is complicated...” Manager within the drug allocation department of the Ministry of Health

“Those are factors of resistance. If the innovation is complicated it is difficult to realise it. It is necessary to simplify usage protocols when dealing with people who are often illiterate.” Communication officer of a national NGO

“I remember the editor of the Observer had brought up this topic at a conference: had tried to open a page for articles in Mòoré. But since the people have an academic logic, they wanted to build a morophone academy and tried to use too complicated words. At that point nobody understood anything any longer.” Founder and leader of national NGO

“It crucial to speak in a way that is accessible to the population. We did not do this 10 years ago but we are informing the people now.” Member of an international NGO

“Information is not easy to digest; the word means death for the people. Those are new approaches to step back and find appropriate words and reduce them to an understandable language.” Member of an international NGO

Lastly, the impact of public health awareness campaigns undertaken by governmental bodies and non-governmental organisations, and the population's comprehension and good reception of them, also seemed to play a key part in the perception of benefits.

“If we communicate better with the population they will understand. [...] Communication remains the gateway; it is important to have consensus which is key to success.” Technical consultant of an international NGO

Therefore, the sum of these factors seemed to impact on the perceived benefits, which in turn appeared to powerfully shape the level of trust in the technology being deployed. This is a complex dynamic which is constantly evolving over time, with both time and information delays.

Throughout the interviews, it became clear that in the Burkinabé context, the development of trust shapes attitudes towards the introduction of innovations, and

hence is fundamental for the acceptance of the technology in question. However, like the perceptions of benefits, trust is highly individualised and formed by multiple factors, which have a variety of origins. Certain factors emerged from our data as pivotal in relation to GM technology, in addition to perception of benefits:

- General comprehension of innovations;
- Confidence in governmental authorities;
- Attitudes of informal leaders;
- Confidence in the institutions responsible for the technology;
- Context based technology;
- Pressure from the convinced population;
- Rumours from the unconvinced population.

The general comprehension of innovations by the adopting population is an important factor when it comes to trusting a technology. Understanding what innovations are, how they work, and which benefits they bring are also especially important when the technology is extremely complex, as in the case of GM mosquitoes.

“When we strengthen trust, it is always good. Building trust is very important, especially if we don't politicise things. We avoid this in the healthcare sector because it divides the population.” Doctor at a regional hospital

“When it's new people don't understand. They need to understand and generally any new activity that you introduce requires long preparations in order to sensitise the community; otherwise, you will find yourself lone and are bringing in an activity that does not work.” Member of an international NGO

The interviews also showed that confidence in governmental authorities can play a big role in the level of trust of a specific technology. Depending on whether a technology is deployed directly through governmental officials or not changes the relative weight of the influencing factors, but independently of that, given that most health innovations and innovations for health are currently deployed by governmental bodies or through governmental programmes, the association seems close for the Burkinabé adopters at local level. This confidence is strongly

influenced by the robustness of the health system structure in Burkina, which Chapter 7 has shown to be quite weak, as well as by prior experiences with other innovations deployed on the ground. As explained above, these are mainly deployed by governmental bodies and hence the link is very strong. Furthermore, interviewees from within the health system agreed on the fact that governmental public engagement on health related issues has been relatively low in the past decade and any improvement will have an impact on the confidence of the population in governmental authorities.

*“Now, at the local level, there is a phase/a period of information in order to inform the population of the shift towards a specific date, before the campaign begins.”
Communication officer within the Ministry of Health*

“We have feedback because we release press communication on the areas via radio, TV and broadcasts and the whole population is informed.” General Secretary of a governmental administration

“We need to communicate better so that they can understand. [...] In the cities they have radio, television and internet; in the villages it is true that they have radio but there is also the public criers with their tam-tam. This is the better way of communication. As soon as he taps everyone is listening, no matter who. Once the public crier begins to tap in the villages everyone listens in.” General Secretary of a governmental administration

“Firstly, there has been an improvement in the way off communication, for example the sensibilisation campaign by the Ministry of Health.” General Secretary of a governmental administration

“At the level of health facilities, there are mobilizers, public criers and community-based health workers. To introduce a new innovation in the district, the three communication strategies for development are used: advocacy, social mobilisation and communication for change.” Doctor at a regional hospital

Chapter 7 also explains the strong influence of the civil society and informal local leaders within the Burkinabé society, especially in urban areas. The chief of the village, the ‘leader of traditions’ (*chef coutumier*, when separate from chief of the village), the village elders, the religious leaders, the various local associations as well as the village development council all play a key role in the society and their beliefs are strongly respected by the local population. Hence their attitudes and views on whatever is new and introduced within the village is a key influencer of the level of trust in the technology.

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“On the ground, the approaches differ depending on the context. In rural areas, the community-based health workers, that we employ and who are in charge of social mobilisation, are tasked to convince the people to attend the talks. This is what our associations do in the field. If there are difficulties, the CHWs go through the village chief or religious leader for the activities to take place. This approach is the same at the level of our clinic which takes the same route on the ground. They do the mobilisation before and on the day of the activity.” Project Manager of a regional NGO

“Often, [without the acceptance by the chief] the project is lost. We explain to the chief that we are not the decision makers but the community in itself; the soil decides where there is water. Thus, if he refuses access, they will not have drinking water.” District mayor of a city

“We involve the local leaders: village chiefs, deputies, envoys, the CVD of the village, as well as the 'leader of tradition'. So people come because they participate. We need their technical help. The people say: 'there are the traditional leaders'... and then they come. If we have the means this works.” Retired mayor of a mid-sized village

“We use the 'leaders of tradition' and the religious leaders, nowadays also political leaders and associates, a lot [for the diffusion of information]; those are not insignificant elements.” Regional director within the Ministry of Health

“If I take a decision with the chief of the village, the entire populations follows. We organise ourselves by forming a group with the Imam and the Elders. We see what needs to be done and we take a decision to initiate what needs to be done in the neighbourhood.” Chair of CVD of a rural village

“Efficacy of and reaction to the product must be proven but we don't do this. We only speak to the larger public but we need to isolate the people and convince them - and there the leaders can help us.” Regional director within the Ministry of Health

The appropriateness and quality of the technology promotion on the ground also indirectly influences the level of trust. This is by influencing the confidence in the non-governmental institutions delivering the technology on the ground. As mentioned previously, the Burkinabé population tends to be sceptical towards the general introduction of innovations due to the lack of confidence in the governmental bodies. This is related to the political instability that has reigned the country for the last decade. Hence, it became clear throughout the interviews and focus groups, that intense engagement activities by institution developing and deploying the technology on the ground are essential to create the much needed confidence in government institution in order to overcome these diffidence barriers. Many of the interviewees also mentioned that engagement should be based on the understanding of the local context. To facilitate this, the involvement of informal leaders, ‘boundary spanners’ (between groups or stakeholders), early adopters and

civil society groups were seen as very important. Furthermore, making sure that universal, as well equitable, access to the technology were priorities to the institution delivering the technology also appeared crucial and were acknowledged throughout the various interviewee clusters. In contrast, the employment of other direct benefits created by of the technology, and community-based distribution of the technology, seemed to be more a priority of the local level users. It was argued by a number of interviews that a dual approach to engagement and trust-building was therefore needed.

*“Cultural acceptability counts as much as the perception that needs to be overcome.”
Regional director within the Ministry of Health*

*“There is no universal criterion [for acceptance]. It all depends on the communities, on innovation and on many factors that can influence and vary from one community to another. The things that are appreciated are not always the same. This depends on the range of values of the communities; there are different values between the communities.”
Communication officer of a national NGO*

“We have worked intensively within the community world, with associations and groups. We have trained them on family planning, equipped them with information and with messages for their communities.” Technical consultant of an international NGO

“[This is] a transversal work on community input. For us it is important to reform and innovate but this needs to come from the base. Until now, we have seen reforms that are coming from the top - top-down. But they implement reforms that are removed from reality. This means that we do the planning and the innovations based on the concerns of the decision makers and not based on those of the population.” Founder and leader of national NGO

“Some people in the community will always be afraid and others will agree to join. The former will encourage the others, despite the risks.” Representative of a civil society group

The development of a context-appropriate technology was widely regarded as an imperative to foster the level of trust. As discussed in Section 7.2.1, the culture and beliefs of the Burkinabé population are strongly rooted in their ethnical traditions and many spiritual rituals are still actively preformed and kept alive. Hence, developing a technology that can be embraced and does not clash with those beliefs and routines was viewed as crucial. This should obviously not just be focused on the hard (essential core) components of the technology but on the soft ones – that is, those that are malleable to local context – as well.

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“At first, we are suspicious of any change, that's cultural. We do not know which kind of changes this will create. As you are not sure if you can manage this, you remain suspicious and observe. [...] In order to bring in something new we need to study the environment because the suspicion is mainly cultural; [it remains] until the innovators prove it to us. We need to take into account the cultural aspects, the perception of the product, accessibility and also the support of the population.” General Secretary of a network of NGOs

“It depends on the innovation whether it embraces the cultural aspect or not. If there are no cultural problems it can pass without problems. [...] If innovation mixes with the cultural [dimension] it is necessary to cut that link.” Retired health professional

“All these erroneous socio-economic and cultural conceptions mean that we still have these health problems at all levels. It takes a lot of communication to get people to accept, to understand, and that's where we can get results and reduce disease.” Executive manager within the Ministry of Health

The strong community sense ingrained within the Burkinabé society, as well as their oral traditions, mean that people place considerable value on the opinion of peer groups, so individual acceptance within those groups is of outmost priority to the Burkinabé population. This puts a particular focus on both the effect that both peer pressure from the convinced population (i.e. who believe in and are convinced by the innovation) and any rumours from the unconvinced population can have on the general level of trust within the population.

“If it is good they will communicate with each other. By word of mouth, people will come.” Representative of a civil society group

“If you say something, the rumours are starting and the opposite message returns. Like for the refusal of generics: if the doctor does not prescribe it, then the word will pass and will be transformed by word to mouth. Nobody will verify.” General Secretary of a network of NGOs

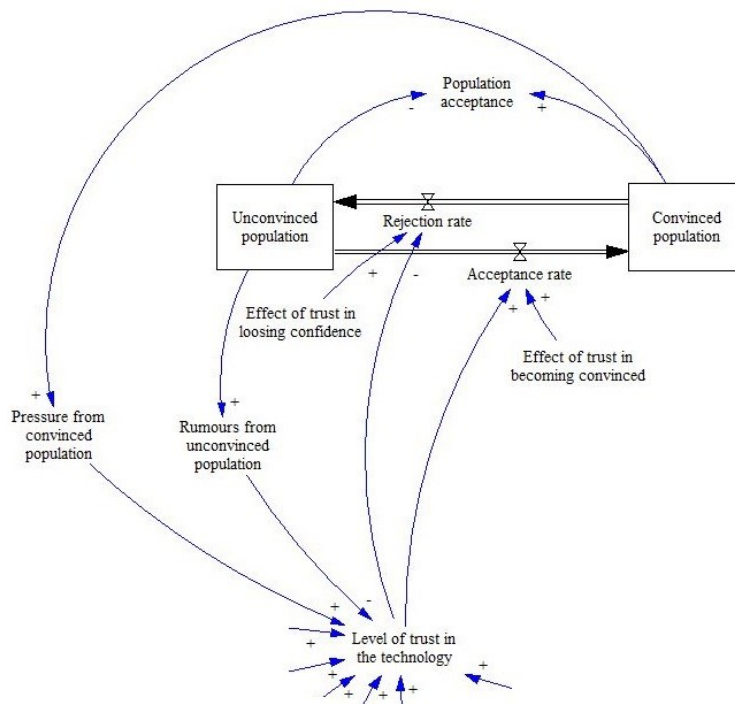
Population-level acceptance loops

Figure 34: Overview of the population-level acceptance loops of the detailed qualitative SD model for the analysis of the adoption of GM mosquitoes in Burkina Faso for the eradication of malaria.

As described in Section 9.1, SD models involve causal loops describing the dynamics of the system as well as stocks and flows describing the state of the system, giving it inertia and providing it with memory. In this part of the model, the author conceived the overall Burkinabé population as a stock variable, which was subdivided into a convinced and unconvinced population stocks. The rates of acceptance and rejection of the technology determine the flows between the two population stocks. The balance between the convinced and unconvinced population leads to the general level of population acceptance towards the technology. Both the rate of acceptance and the rejection rate determine the state of the system at any given time. These rates are principally influenced by the effect that the level of trust has on either losing confidence or in becoming convinced.

As described in Section 2.1.3, the general innovation literature (Chapter 2) conventionally highlights the role of other factors, including cost, on the acceptance and rejection rate of health innovations. Within the Burkinabé context and in the case of GM mosquitoes, these other aspects did not emerge in any of the interviews

or focus groups, either spontaneously or after prompting. Hence, the author decided not to include these factors within the boundaries of the model. However, it is recognised that they may play a role which has just not emerged yet, once the introduction of GM mosquito technology moves into a more mature phase and its costs become more visible.

The data showed that the two stocks also have reinforcing effects on the level of trust. As mentioned in Section 7.2.1, the Burkinabé population is embedded within a hierarchical culture, where social acceptance is crucial and which emphasises the importance of belonging to groups and unions. As an effect of this culture, these social dynamics play an extremely important part on the level of trust of individual members of the population, enhancing the effect of pressure from the convinced population or rumours from the unconvinced population on the individual level of trust and in return on the acceptance and rejection rates.

“When we use good channels to convince them we do not encounter problems.” Manager in a regional CMA

“There are also rumours that are started by an individual within the population, a self-proclaimed expert, who could be semi-literate, close to a health worker or knowing how to read a little and who could distort or scandalise information. This can often be the source of the refusal of an innovation.” Qualified nurse at a local hospital

Conclusions from the population acceptance and understanding loops

As explained in Section 6.1.4, given the current stage of development of the Target Malaria project and the way it has evolved over the past few years, it was not possible to interview the Burkinabé population retrospectively on their experiences of the adoption of GM mosquitoes – the technology has yet to be deployed at scale. Hence, the author partly developed the model based on experiences of the adoption and diffusion of previous health innovations. These, however, are generally rather different from Target Malaria’s technology in that they require an *individual* adoption decision once the government has already decided to implement that innovation on the ground – a decision to acquire and use a bednet or be vaccinated is rather different from the deployment of an innovation into a community on a

collective basis, such as fluoride in the water supply or GM mosquitoes. These, like most

Like for some other public goods, the peculiarity of the GM mosquito technology compared to other health innovations is therefore that adoption decisions are not directly made by individual members of the population, but by governmental authorities, which decide on whether to release those mosquitoes for the benefit of all. On one hand this makes the technology extremely equitable as everyone can benefit from it. On the other hand, it does not allow direct individual choice on the uptake. Nevertheless, acceptance and uptake of a technology are intrinsically linked, as one is the prerequisite for the other – no individual would freely take up an innovation if they did not accept it.

Therefore, it is reasonable to use lessons on factors influencing individual uptake of previous innovations to help elucidate potential acceptance of the GM mosquito technology. However, unlike previous innovations, the population's acceptance of this technology is not the end point for its adoption at country level, since in this case deployment and adoption is governed by regulators and the government.

It was therefore decided that the boundaries of the model needed further expansion to capture wider factors influencing adoption of the GM mosquito technology, focusing on the decision maker level. This would help to better understand the dynamics behind that process, and the relationship between these factors and population level acceptance. For this, the author conducted further interviews with regulatory experts in order to understand those dynamics and the inter-relationship between the two levels.

9.2.3 Institutional impact: policy and regulatory level

As explained in Section 6.1.4, at the time of the interviews the Target Malaria project had just submitted its first application to the national biosafety authority for the contained use of sterile male mosquitoes in Burkina Faso. Understandably, it was deemed not appropriate from the project's perspective for the author to directly interview the regulators on their views of the key factors influencing the adoption of

the technology they were currently reviewing. For this reason, the author decided to interview a range of international experts on the regulatory processes for GM products in Burkina Faso. Since a retrospective view was not possible, the interviews were focused on the stakeholders' perceptions of the key factors based on their prior experiences of GM technology. In fact, one regulatory expert had extensive experience on importing GMOs for agriculture into Burkina Faso, while the other with the introduction of mosquitoes created using different GM technologies in other contexts.

Chapter 2 elucidates how new product development (NPD) frequently involves iterative and non-linear processes, especially where complex technologies are involved. In the case of GM mosquitoes, it is clear that the development, deployment and adoption of the technology are highly interlinked due to the innovative nature of the final technology (self-sustaining GM mosquitoes) as well as to the different phases and stages required to reach that goal (see Figure 35).

For this reason, within the SD model at policy and regulatory level, the author conceived of the NPD process for GM mosquitoes as stock variables in terms of progress from original idea of a potential technology towards a fully-adopted innovation within Burkina Faso. These comprise the three phases of technology development (self-limiting sterile male, self-limiting male bias, and self-sustaining male bias or fertility gene knock out), as well as the various testing stages for each phase as described in detail in Section 6.1.4. Each of these phases entails R&D activity both outside and inside of the targeted context (in this case Burkina Faso), as well increasingly large scale studies in the field, requiring the deployment of prototypes, followed by further R&D work. These also require various regulatory approvals at different stages which would allow for further concrete steps in terms of adoption. In the stock and flow diagram (Figure 35), this process is represented by the product development progression rate. This is an iterative process until the final technology is reached.

Given the current stage of the overall Target Malaria project, the author included the adoption rate of the final technology within the model boundaries, but the focus of the PhD study was solely on the factors influencing the journey between potential

technology and final technology ready for adoption. Nonetheless, because of the interlinked nature of NPD in this case (i.e. R&D and field trials are continuously occurring), this progression should be seen as a fundamental building block for mainstream adoption.

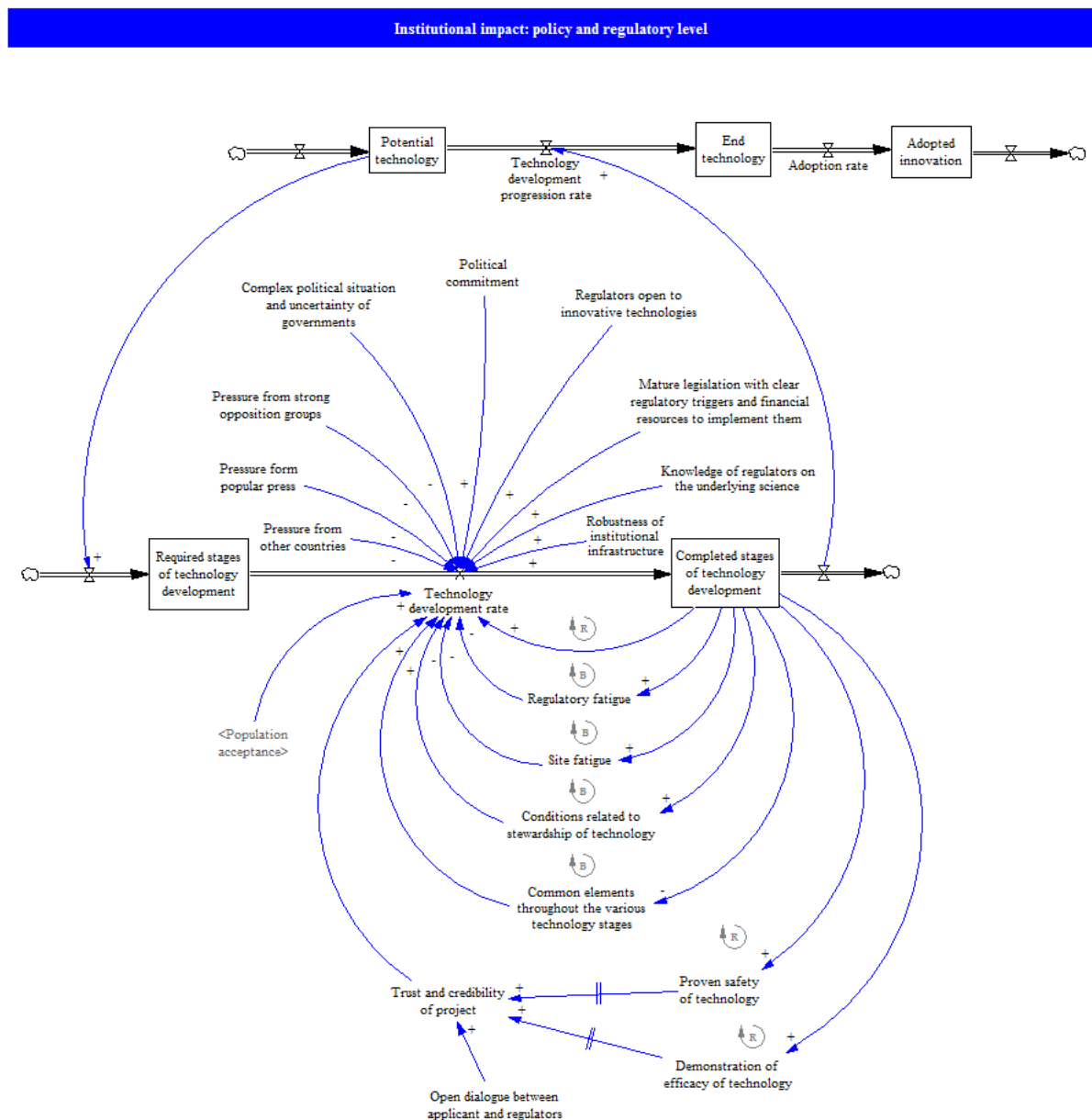


Figure 35: Institutional impact - policy and regulatory level of the detailed qualitative SD model for the analysis of the adoption of GM mosquitoes in Burkina Faso for the eradication of malaria.

Through the interviews, a number of factors at the policy and regulatory level which influence the product development progression rate were identified. These factors

were deemed by interviewees to be constant throughout the whole process (in between stages and phases), but their relative contribution appears to vary as the process unfolds.

Figure 35 shows that the product development progression rate can be represented by a stock and flow relationship between the remaining *required* stages of technology development and the *completed* stages. These are connected through a product development rate. In other words, at any given time a certain proportion of the total effort needed to reach the stage of the final technology will have been expended. Hence, the *faster the product development rates* of each of the stages, the *faster the progression rate* from potential technology to final technology.

At the time of the research, Target Malaria was reaching its first milestone, involving the importation of the first intermediary stage of the technology (self-limiting sterile males) to Burkina Faso.

Throughout the interviews, several exogenous factors emerged as influencing the product development rate. These can be clustered as external resistance factors as well as the readiness of the institutional and political context. Furthermore, also a number of endogenous factors, resulting from the completion of the various technology development stages clearly emerged from the statements of the interviewees. These can be grouped into *reinforcing iterative learning processes* and *balancing fatigue-generating loops*.

The exogenous, external resistance factors that the interviewees deemed to play a significant role were mainly peer pressure factors from external groups, including other countries, the popular press and opposition groups. These groups have exercised in the past a major influence on the decision making structure at policy and regulatory level and are expected to do the same for GM mosquitoes. It was felt that this would be increasingly so, as the technology progresses towards the adoption of self-sustaining strains. Withstanding this pressure was seen as not trivial and potentially a significant barrier to further development and adoption of the technology.

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“[...] opposition groups. They have a lot of money to spend, and a lot of effort that they can use to oppose and that’s been a problem all along especially in countries in Africa where you have well-funded opposition groups going up against these regulatory agencies.” Regulatory affairs specialist

“Anybody who is ideologically opposed to a genetic modification may support local people on the ground - and have done frequently.” Regulatory affairs specialist

The remaining exogenous factors identified as key enablers or barriers to the product development process of GM mosquitoes were of different nature, but were all based on the institutional and political context readiness of Burkina Faso.

Political commitment was considered important and necessary, not only because of the political will to implement the technology on the ground once a regulatory approval is given, or as backup support of the regulatory bodies decision towards the broad public, but also intrinsically due to the practical regulatory process behind the adoption of GM mosquitoes as described in Section 7.2.4.

“In Burkina you’ve got a ministerial sign off so you have to have that political will, they want to see this project go ahead, they want to do this politically, otherwise it will influence regulatory, if they have a negative public comment period.” Regulatory affairs specialist

“I think it [political engagement or commitment] would be very applicable here. I think it will work in a positive way also for us also because of the burden of malaria.” Regulatory affairs specialist

The readiness of the regulatory bodies and local legislation was also expected to be crucial. In fact, the interviewees viewed a mature legislation with clear product and process-based regulatory triggers, and the much-needed financial resources to implement them, as a key part of the infrastructure needed on the ground. Furthermore, the readiness of the regulatory bodies in terms of general openness to complex and potentially controversial technologies was also a factor deemed important and which should not be taken for granted. Additionally, especially for complex technologies, the preparedness of the regulatory bodies in terms of their knowledge of the underlying science to that technology, or their ability to gain it from trusted impartial external sources, was also held to be a key factor.

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"I think this is driven totally by what your regulatory trigger is. So in order to produce a dossier, you have to know under which law you are applying, and what the procedure is. So, some countries have the genetic modification as such. [...] You have to apply because it's genetically modified, so that's a process-based trigger. Other countries have a product-based trigger, so this product does vector control and there may be other legislations that are triggered because of that." Regulatory affairs specialist

"Nevertheless, even if you have a sound legislation [... you may...] have no resources to implement it." Regulatory affairs specialist

"What helps regulators is knowledge. So if you got knowledge, whether it's from published papers or from doing the same thing in other countries, whether it is from other people doing the same thing, which helps them come to an easier decision." Regulatory affairs specialist

"Just the uncertainty of governments. Right now Burkina Faso is in a good place as far as their regulatory structure not being too affected by what has happened over the last few years politically. It seems like Burkina Faso has managed to keep going despite some political upheaval, but if things should change drastically, I think that could cause a problem." Regulatory affairs specialist

All these factors were also expected to enhance, and be enhanced by, the robustness of the institutional infrastructure behind the policy making and regulatory bodies. This included not just a readiness of all the required bodies, functions, evaluation procedures and laws, but also a certain degree of flexibility of them in order to be able to adapt to request to address them in the best possible way.

"The ability of the NBA to conduct the assessment of the application and the evaluation of the application, in a way that gives them the confidence that they've done their job properly. And that includes the confidence that they conducted a proper risk assessment to take the decision." Regulatory affairs specialist

"Regulators should be allowed to make decisions based on analyses and risk assessments they do themselves and make sense to them, because those are the ones they will be best able to defend." Regulatory affairs specialist

"This should include someone who makes sure that the decision making process and the transmission of the documents and consideration of the documents is done in a timely way and doesn't let things lag behind." Regulatory affairs specialist

As mentioned previously, in addition to the exogenous factors the interviewees also mentioned a certain number of endogenous factors as crucial to the adoption of the technology in Burkina Faso. These arise from the completion of the various technology development stages and influence the technology development rate. In fact, the completion itself of a development stage seems to have an impact on the

technology development rate with a reinforcing effect, i.e. the more stages are approved, the more the regulators and policy makers are aware of the technology and have invested faith in it, and the more confidence they have in the upcoming stages, the higher the product development rate. This obviously implies there was a positive outcome of the prior stages.

Furthermore, the more positively completed stages of technology development, the more the safety of a complex and potentially controversial technology can be proven by the researcher team, so the more trust and credibility the researcher team will have in the eyes of the regulatory and policy making bodies. This, in turn, leads to an improved product development rate.

"Safety should be intrinsic to the product, providing evidence that this thing is going to work and that it is worth the enthusiasm that they will have for this technology and the effort they will have to support the deployment of this technology by rendering positive decisions." Regulatory affairs specialist

Similarly, in the case of the demonstration of efficacy of the technology, the more stages have been successfully completed, the more efficacy can be proven, hence the greater the regulatory and policy making bodies' trust in the researchers and the technology. As with the safety loop, this leads to an improved product development rate, creating a further reinforcing loop.

"One thing I wouldn't necessarily call hurdle or barrier, but it's something that a project necessarily has to be successful at – is the demonstration of efficacy. Providing evidence that this thing is going to work and that it is worth the enthusiasm that they [regulators] will have for this technology and the effort they will have to support the deployment of this technology by rendering positive decisions. So I think that's something that you really need." Regulatory affairs specialist

Through the interviews it also became clear that there was also another exogenous variable which influenced the trust and credibility of the project. This was the extent of an open dialogue between applicant and regulators. The more the scientists share and are frank and upfront with the regulatory and policy making bodies, the more they can trust them leading to a climate of mutual acceptance.

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“Trust and credibility. So if you put in an application which you have to change and say “well, sorry we got that wrong” it doesn’t look like you’re very trustworthy, like you’ve not got much credibility, because to a regulator it seems you might not know what you’re doing.[...] It’s about building up a dialogue, trust, a rapport with the regulator, as well. So they understand you, they trust you, you know, they trust the messenger.” Regulatory affairs specialist

Nevertheless, despite the reinforcing loops enhancing the product development rate, the interviewees mentioned a number of barriers affecting the product development rate which took the form of balancing loops. First, the complex nature of the technology requires a multifaceted and stepwise approach to development, involving multiple iterations, before actually being able to deploy a final technology that can be viewed as a long term solution to the imminent malaria problem. Hence, the more the required and completed stages of technology deployment, the higher the degree of ‘regulatory fatigue’ – exhaustion due to time and resources spent addressing regulatory requirements – and the more difficult it becomes to keep up momentum. This was felt to potentially slow the product development rate.

“Regulators have the obligation to consider whatever application they are submitted to them, but certainly it makes them much more engaged and enthusiastic, if it is an application for a technology that they know is going to do something really beneficial.” Regulatory affairs specialist

“Regulators tend to look at what’s in front of them at the time. They don’t tend to think this is a program. Developers might think it’s a program, but they tend to look at the dossier in front of them at the time. So I think one of the barriers that might be encountered is the release of genetically modified insects is seen as quite controversial. If that doesn’t provide any benefits to those people, i.e. we’re not getting rid of malaria through precursor stages of the technology, then why releasing....so if they don’t perceive a benefit to them it becomes tricky.” Regulatory affairs specialist

“It happened in Malaysia. They wanted to do it in a very controlled way, but after the first trial it stopped, because nobody could see any benefit. Not because there wasn’t one, just because the trial wasn’t designed to produce these benefits.” Regulatory affairs specialist

“The perception of what this technology is going to bring to you is crucial.” Regulatory affairs specialist

A similar effect can be viewed in the general population and especially around the field sites where the open field releases of the intermediary technology phases will be tested. The more of these stages are needed and completed without actually

bringing a concrete, effective and long-lasting solution to the field, the more the site fatigue kicks in, again slowing the product development rate.

“There might be a boredom with those [engagement] conversations after a while, what calls site fatigue, especially if things get further and further delayed, so, you know, in here if we spend ten years in a regulatory process trying to get it approved, then they’ll say “yeah but you said it would come ten years ago, why isn’t it here, what’re you doing, you do not know what you are doing...” you know, that sort of thing particularly if you’re still trapped in the villages or still trying to get data out to those villages, then there’s a sort of fatigue element that sets in and they say “oh go away you’re never going to bring me this stuff. I don’t want you here in my village anymore.” You know that could be a possibility.” Regulatory affairs specialist

The more complex the nature of the technology going through the product development process, the more stages of technology development are required to be completed. Given the increased risks associated with a complex and novel technology, regulators are likely to attach more stringent conditions related to its stewardship. In certain cases, these may be only extremely difficult if not impossible to fulfil by the project team, leading to a slow down or total halt of the product development rate, and hence creating another balancing loop. This scenario was deemed as especially marked for low income countries, where the institutional and political context readiness tends to be weak and hence more cautious.

“The further we get along in the process, the higher the complexity, the more they may seek additional reviews, or when we get to a gene drive product, for example, they may say ‘well let’s have a socio-economic review.’” Regulatory affairs specialist

Another downfall of having such a complex product development process and several phases of development is the fact that each further stage has fewer common elements with the original starting technology and the previous stages that the regulatory and policy making bodies have just taken a decision on. This is a strong feature of the various development phases leading to a self-sustaining transgenic mosquito strain. This is fairly different from the usual product development process for more standardised innovations like new drugs. The more regulators are confronted with new concepts and theories, the more they need to understand the implications, leading to a further slowdown in the product development rate.

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“But I think what’s different from gene-drives is normally [...] I mean this is what we’re doing here, we’re building up credibility and information with the committee, but they are 3 separate products, normally you’d have the same product that you take through each of the steps, but we’re just doing step-wise in a different way. So the product that you want release at the end, the gene-drive product isn’t the same as the product that you are seeing now, which is male sterile. And so what we’re trying to do is to make sure they recognize elements from the male sterile that are equally applicable to gene-drive, such as the marker gene, for example.” Regulatory affairs specialist

Despite all this, the factor deemed to have the strongest impact on the product development rate, not only by the regulatory experts, but also by many national interviewees at decision making level, was population acceptance. Given the current socio-political context in Burkina Faso, this factor was not only considered as extremely important but also as overshadowing all the other factors. In fact, it was thought to be so crucial, that even despite all the other factors being taken into account, a lack of population acceptance could completely stall the product development rate. This creates an extremely powerful link between the ‘population acceptance and understanding’ and the ‘policy and regulatory’ levels and putting the population acceptance variable in the spotlight and clearly making it to something that all the involved players (i.e. policy makers, research funders and the research and development community) will need to take into consideration.

“And I think the final factor that I would say is just good public engagement [...]. I think it is so key to the acceptance and adoption of a technology. As in fact, the population acceptance plays a major role.” Regulatory affairs specialist

“[Population acceptance] and its impact down the regulatory system: I think it makes the job of the regulators a lot easier if they aren’t faced with making a decision that is going to be so unpopular to the public that they are going to have a difficult time making that decision.” Regulatory affairs specialist

“The thing that comes most to mind is once again the importance of public acceptance. Everything falls apart if there is no public acceptance.” Regulatory affairs specialist

Evidence and trust loop

As can be seen from the overview diagram of the qualitative system dynamics model (Figure 30), there is a further connection between the two levels of the SD diagram, the ‘policy and regulatory level’ and the ‘population acceptance and understanding level’, which has only been indirectly taken into consideration until now. The so

called 'evidence and trust' reinforcing loop in fact shows how intertwined the two levels are. Each of the completed stages of technology development changes the perceived impact of the technology over time through the generation of evidence of tangible short and long term benefits or detrimental side effects. As described above, the perceived benefits of the technology impacts on levels of trust, which have a major influence on population acceptance.

9.3 Discussion

The qualitative system dynamics model outlined above was developed through the use of systems thinking with the aim of understanding the key factors and dynamics leading to the development and adoption of Target Malaria's GM mosquitoes within the Burkina Faso context. However, in addition to specific lessons for this particular technology innovation, the qualitative research and SD model helps to reinforce findings from existing literature on the adoption of complex health innovations.

The main findings arising from the model can be subdivided in three categories:

- General innovation adoption findings;
- Burkina Faso innovation findings;
- GM mosquitoes innovation findings.

Summary of findings from the modelling on general innovation adoption factors:

In general, all components at different levels in the system dynamics model – ranging from individual through population to policy and decision maker – are interlinked via the reinforcing and balancing loops which determine the dynamics of GM mosquito technology adoption within a complex system. These interactions have either amplifying or balancing effects on each of the components, creating a network of feedback loops which determine the system's behaviour and generate potentially non-linear responses and variable time lags between cause and effect of actions. The model shows that for such a complex technology there is effectively a strong multi-way interaction between problem perception, the broad context (contextual factors), the characteristics of the health system in question, the institutions within the health system, the adoption system, and the adoption entities which need to be taken into consideration. Using linear perspectives to describe these dynamics would lead to a simplistic analysis and misinterpretations of the factors, making it impossible to correctly forecast consequences of interactions within the system.

Some of the factors influencing the adoption process of innovations described by Everett Rogers (1962) (i.e. trialability, compatibility, observability, relative

advantage, and complexity) (see Section 2.1.4) have indirectly emerged as important aspects throughout the interview analysis process and have been reflected in the SD model. The compatibility of the technology with the local context and culture is a key factor influencing the level of trust within the technology. Likewise, the author believes that observability – the degree to which technology usage and impact are visible to others – plays a role in the perception of benefits of the technology. The degree to which the innovation is difficult to understand and use - i.e. its complexity - in this case has not only been shown to influence the individual and population acceptance of the technology, but also to create a series of balancing effects on the product development pipeline at policy and regulatory level.

Analysis of the interviews also suggests that some of the characteristics of potential adopters (e.g. values, attitudes, and interests) or non-adopters (Moore, 1991) have an indirect impact on the acceptance of the innovation, and influence the balance between the convinced and unconvinced population. This because in the Burkinabé context the social group identity and belonging are extremely important.

Several resilience factors emerged from the data, which have also often been described in the literature on scaling up health interventions in low-income countries. These are:

- Organisational readiness of the adopting system;
- Sustainability and equity of the proposed intervention;
- Adaptation of the technology to local needs and cultures;
- Use of local evidence and regional best practices;
- Enhancement of knowledge transfer;
- Development of strategies to overcome human resource constraints;
- Engagement with local, national and international stakeholders in all phases of adoption process.

Summary of findings from the modelling on Burkina Faso innovation adoption factors:

The importance of the resilience of health organisations, institutions or systems for the successful introduction of innovations or other healthcare interventions are exhaustively described in the literature. This research has not only highlighted the importance of these factors in a specific national context, Burkina Faso, but the complexity of the interrelationships between them. In contrast to the general innovation research literature, much of which typically focuses on the impact of individual factors on innovation adoption, this research has found that in the Burkina Faso context multiple resilience-related factors interact with each other and have a strong impact on the comprehension of innovation and health issues. This, in turn, is reflected in the population acceptance level.

The fact that traditional beliefs, the social structure of the community and informal leaders within it play a key role in the adoption of health innovations in low income countries has already been acknowledged in the literature. Through the in-depth qualitative research performed at a 'local user' level, and the trust built with stakeholders through initial informal meetings, the author was able to gain a detailed understanding of *the way in which* the Burkinabé social and cultural factors impact on the understanding of GM mosquito technology and on the perceptions of its potential benefits, as well as the level of trust held by the population towards both this particular innovation and health innovations more generally.

Another nationally specific factor influencing the adoption of health innovation is the lack of political stability over the past decade in Burkina Faso and the resulting weak health system, plagued by strong inequalities. The interviews and the modelling allowed the author to understand more precisely how the robustness of the health system played a crucial role in the level of trust the Burkinabé are willing to place in health innovations, as well as their use of the formal health system more broadly. This second factor is very important, as it indirectly influences the general comprehension of the Burkinabé population of health issues and of innovations, through the resilience, awareness and knowledge loops. This has not been previously described. Together, an understanding of these details gained from the

research in Burkina Faso was critical to enrich the model and uncover the detailed dynamics of this complex adoption system.

Summary of finding from the modelling on GM mosquitoes innovation adoption factors:

The complexity behind Target Malaria's technology has been recognised as a barrier in the model, supporting prior literature evidence. Not only is this technology intrinsically complex in both its hard and soft components, but it is also difficult to explain how it works to the general public. This leads to a high cognitive distance between technology developers, regulators and users or beneficiaries in the population. This distance is further enhanced by the lack of technical words in the local languages spoken on the ground in Burkina Faso. This complexity does not only influence the population acceptance of the technology by impacting the perception of its benefits but it also affects the policy and regulatory level. This is because complexity also means the technology is viewed as controversial, reinforcing general perceptions and the historic debate on GM and its implications for risk and benefits. Because the technology is viewed as controversial, there are strong opposing views which are hard to counteract with scientific evidence. This leads to powerful external resistance factors, as well as fatigue at decision making level. This is reinforced by the numerous safety reviews which need to be carried out for each project development stage, all potentially slowing the product development rate.

Van de Ven theorised that new product development processes are frequently 'messy' and non-linear due to the complexity of the technologies being developed (see Section 2.1.4) (Van de Ven et al., 1999). This study has shown the close relationship between the phases and stages of product development and the adoption of the technology on the ground. In particular, this is due to the innovative nature of the technology – self-sustaining GM mosquitoes – as well as the different phases and stages required to reach that goal (see Section 6.1.4). The author has established that this takes place through the cumulative impact of evidence for benefits or detrimental effects generating trust in the technology and ultimately

influencing levels of acceptance. The NPD process for GM mosquitoes therefore appears to be an extreme example of health technologies which involve iterative development processes.

Another peculiarity of the GM mosquito technology development process is that the range of factors which influence the product development rate (and hence the speed of progression towards an end technology) at policy and decision making level seem to remain constant throughout all the phases and stages of development. The only aspect that varied over time is the relative importance of the individual factors. For example, the knowledge of regulators about the science, and peer pressure from the popular press and opposition groups, are significant factors influencing the progress of the technology through its development stages. But as time progresses the relative importance of the regulators' on the scientific knowledge declines as they learn while they move forward in the process, while the importance of peer pressure grows as the gene drive constructs become more concrete. This finding has not been previously highlighted in the research literature.

Finally, many previously studies of global health technologies rely on individual adoption decisions. As already noted, GM mosquitoes are public goods and are therefore exceptional, as adoption decisions are not directly made by individual members of the population but by governmental authorities, which decide on whether to release those mosquitoes for the benefit of the entire population. This peculiarity leads to an extremely equitable technology on the one hand, but on the other hand leaves no individual freedom on choice of uptake. The model has shown that acceptance of the technology at a population level is *the* major factor influencing the *product development rate*, not previously highlighted in the literature. Moreover, the study was able expand on the prior literature by demonstrating that factors influencing individual choices about adoption are the same as those leading to population acceptance of such technologies.

10 Discussion and concluding remarks

The aim of this chapter is to outline the key contributions to the extant literature, as well as to draw conclusions on the findings of this PhD study and to depict the resulting policy and practice implications. It also discusses the limitations of this PhD study and outlines potential future research steps. Section 10.4 and Table 17 provide a summary of the key findings in relation to the original research questions. The findings and how far they answered the research questions are described in detail below.

10.1 Summary of PhD study

Although there have been significant improvements in recent years, in 2015 almost half the world's population was at risk of contracting malaria and 438,000 malaria deaths were recorded, the overwhelming majority in Africa. The continuing burden of malaria is exacerbated by the limitations of current technologies, notably growing resistance to insecticides and medications, as well as difficulties in deploying the interventions on the ground. These limitations have emphasised the need for a new, innovative technology which can provide an intervention that is cost-effective, sustainable, area-wide, and equitable. An example of such an innovation is currently being developed by the research consortium 'Target Malaria'. If successful, the resulting technology will be self-sustaining genetically modified (GM) *Anopheles* mosquitoes, which lead to a progressive reduction in the numbers of native malaria carrying mosquitoes until there are too few remaining to sustain transmission of the disease. The Target Malaria technology could therefore be a very significant innovation, complementing other malaria elimination tools. However, this technology is scientifically challenging to develop and controversial to deploy. Its implications are only partially understood because of the novelty of the technology, and an extensive programme of development and testing is needed.

The aim of this PhD study was to better understand how complex health technology innovations are adopted in low-income countries. This was achieved through a

study of the adoption and implementation of Target Malaria's innovative technology for malaria elimination in the Burkina Faso context. The author chose a mixed methods approach, combining qualitative and quantitative data, including system dynamics modelling, to understand the dynamics of socio-economic, policy and regulatory factors that influence the implementation of this novel health technology.

Previous experience of the introduction of complex, innovative health interventions indicates the need to understand the relationship between the technology, the health system and the wider socio-economic context in shaping adoption. The starting point for this PhD study was the idea that adopting and embedding complex health technologies can only be understood through analysis of the interactions between the different components of the political, social and economic system taking up the innovation and its dynamics. For this reason, a holistic framework, drawing on a systems thinking approach, was adopted to guide the research and analysis.

Primary qualitative data mainly originated from focus groups and interviews with 74 purposively selected stakeholders with very different backgrounds, ranging from rural villagers in Burkina Faso to Burkinabé policy makers and international GM regulatory specialists. Based on this data, qualitative system dynamics model was developed to understand the behaviour of the complex system within which the GM mosquito technology is being introduced.

Secondary quantitative data was sourced from the USAID DHS Program and enabled an econometric analysis of the socio-economic and demographic factors influencing the past adoption of malaria prevention and elimination technologies in Burkina Faso.

A comprehensive analysis of the Burkinabé health system, as well as of the broader national context, was carried out in order to gain a more profound understanding of the socio-economic, cultural, healthcare-related, and technological landscape in which the case study was embedded.

This work allowed the author to understand and compare the specific factors to the adoption of the GM technology in question and which are in common with other more conventional malaria elimination tools within the same context, i.e. Burkina Faso. Comparison was also made with the general literature on factors influencing adoption and diffusion of health innovations.

10.2 Contribution to knowledge and extant research

This PhD study has made several contributions to the existing research on the adoption of innovation in health systems. There has been previous work on the challenges of deploying complex health interventions in low-income settings. However, these do not involve technologies that are as complex, novel and controversial as GM mosquitoes, and where there is also a simultaneous development and deployment of the technology.

A major contribution of the thesis lies in the application of qualitative system dynamics modelling and system thinking to the case study of the deployment of the Target Malaria project technology in a real-world setting, i.e. Burkina Faso. To the author's knowledge this is the first detailed application of such an approach in the context of a developing, African health system. The modelling (in Chapter 9) has helped to advance our knowledge of the complexity of the relationships and dynamics between health technology, the health system and the wider socio-economic context which shape adoption, and also the intrinsic complexity of each of the individual system components. This has led to four key findings, which are detailed in Sections 10.2.1 to 10.2.4.

10.2.1 Interconnection between the development and adoption processes

From the analysis of the case study and the qualitative system dynamics modelling it became clear that in addition to the standard factors encountered in the successful deployment of health innovations in low-income countries (e.g. context appropriate technology, robustness of health system, and public health awareness), the

adoption of a novel and highly complex technology is strongly influenced by the *interconnection of the technology development process with the adoption of the same technology on the ground*. In the case of GM mosquitoes, the pathway from potential technology towards a fully adopted innovation is closely intertwined with the adoption process. This is mainly due to the fact that all the three phases of technology development (self-limiting sterile male, self-limiting male bias, and self-sustaining male bias or fertility gene knock out), as well as various testing stages for each phase, require close engagement of the local policy makers through regulatory approvals, and acceptance by the local community for technological development on the ground. This process is explained in detail in Section 6.1.4 and visually represented in Figure 18, which shows the technology development phases and stages which are performed in Burkina Faso and the relative technology adoption level, i.e. progress towards the final product. This phenomenon is triggered by the intrinsic complexity of the technology's hard and soft components, as well as its extreme degree of innovativeness.

The qualitative system dynamics modelling has also shown that the length of the technology development process poses potential barriers to adoption and hence plays a role in the speed and quality of the uptake of such technology. Especially important are the emergence of external resistance and fatigue at both the decision making and population levels, partly due to the perception of limited feedback of direct benefits in the earlier stages of technology development. Further, this process also has a direct impact on the level of trust in the technology that can be built up.

This finding has policy and practice implications for the research team delivering the technology which need to be taken into consideration and go beyond the usual R&D practices and adoption strategies (see Section 10.3). These implications need to be taken into consideration by the research team together with their potential long- and short-term consequences. Because of this, the use of a qualitative system dynamics model and system thinking are invaluable for highlighting the possible unintended consequences or counter-intuitive impacts.

10.2.2 Interconnection between individual adoption of technology, and population level acceptance and policy maker level adoption

The qualitative system dynamics model has revealed that the nature of the technology, as well as the complex technology development process, mean that adoption is not based on *individual* uptake of the technology but by *governmental and institutional authorities* (i.e. at policy and regulatory level), which decide on whether to release those mosquitoes for the benefit of all. This feature of GM mosquitoes leads to an extremely equitable technology because it benefits everyone once it is deployed, but it leaves no individual autonomy for adoption. Given the past debates on efficacy of GM innovations, this can be viewed as controversial by a number of stakeholders. This feature not only adds a further layer of complexity to the system, but it also differentiates the adoption process from many of the previous studies on global health technologies which involve adoption decisions either by individual users or individual organisations such as hospitals.

The use of the qualitative system dynamics modelling showed the need for a perspective and approach to adoption that embraces a ‘total system’ adoption, at both population and policy maker level. This is due to the fact that population acceptance is the major factor influencing the technology development rate. At the same time, the speed and quality of the completed stages of technology development influence both the endogenous factors affecting policy makers and regulators (i.e. through regulatory fatigue), as well as the perceptions of benefits of the technology by the population (i.e. growing awareness). This last factor also plays a major role in the level of trust the population has in the technology and hence the final population acceptance, closing the loop of interactions between the population and policy maker level.

The study therefore demonstrated that factors influencing individual choices about adoption of relatively simple malaria technologies can be the same as those leading to population acceptance of more complex ones. Hence, when deploying policies and deployment strategies, the research team will need to take all the factors influencing *individual* adoption decision making as well as those affecting

organisational and systems adoption decision making into consideration - neglecting one of those perspectives could have a detrimental effect on the other one.

10.2.3 The importance of contextual factors on adoption processes: health system and institutional readiness

Context is important in shaping the adoption process of complex innovations through its influence on health system readiness (see Section 10.2.3) and through socio-cultural factors (see Section 10.2.4). The qualitative system dynamics model identified two important aspects of the way wider health system readiness affects the adoption process of complex health technologies in low income countries. Firstly, health system readiness plays a crucial role in the confidence of the population in governmental authorities, which in turn influences the level of trust in the technology and hence the population's propensity to accept it. Second, given that in most low-income countries primary health facilities play a crucial role in educating the population on health issues, health system readiness at that level also plays a major role in the general comprehension of health issues, which then reduces the knowledge gap linked to ability to perceive and understand the benefits arising from the technological development on the ground.

The impact of health system readiness on such technologies hence is rather different from what is reported in the literature, where health system readiness is mainly linked to the availability of the technology on the ground or its distribution strategies, or to the general robustness of institutional infrastructure in the country (i.e. regulatory bodies), as well as presence of legislation with clear regulatory levers and financial resources to support innovation implementation.

Further, the general political instability over the past decade has certainly slowed down the general development of the country, leading to a series of socio-economic barriers like unemployment, poverty, inequalities, low education, and high disease prevalence.

All these factors indirectly impact on the uptake of complex health technologies, as they have a reinforcing negative effect on the general comprehension of innovations and health issues, and consequently on the perception of benefits such complex technologies can bring as well as on the level of trust the population holds in such technologies. The political instability has also led to poor health system infrastructure, impacting on the health system readiness and the implications mentioned above.

Nevertheless, despite the poor resilience and low system readiness, Burkina Faso has proven that some of the contextual barriers can be overcome. In fact, despite its difficulties, the country has strong pre-existing regulatory structures which are crucial for the evaluation and adoption of the technology on the ground.

10.2.4 Influence of contextual factors on adoption processes: socio-cultural factors

In the case of Burkina Faso, the strong traditions still deeply rooted in the Burkinabé culture impact the adoption of complex technologies in several ways. The hierarchical societal structure plays an important role in shaping the communications and deployment channels that need to be used when developing and deploying complex health innovations on the ground. This has policy and strategy implications for the technology developers delivering the technology on the ground. Another implication of the Burkina Faso cultural context is the almost non-existent problem perception of malaria amongst the Burkinabé population, as malaria is viewed as a widespread, common disease, mostly irrelevant and curable. This is magnified by the fact that there are still a large number of misconceptions around malaria which are deeply rooted in the Burkinabé culture. In fact, the majority of malaria symptoms besides fever are often attributed to other illnesses which are usually thought to be caused by evil spirits or supernatural causes.

10.2.5 Other contributions to knowledge

This study has also contributed to the knowledge on the adoption process of more widely applied malaria elimination technologies, as well as to the literature on the adoption and diffusion of malaria elimination technologies in sub-Saharan Africa. This was achieved through the econometric study of the geographic, socio-demographic, household, economic, and healthcare-related factors underpinning the adoption of technologies targeting malaria prevention and elimination in Burkina Faso (Chapter 8). While econometric studies of factors influencing the adoption or scale-up of health interventions are fairly common for some African countries (e.g. Kenya and Rwanda) and for innovation in specific domains (e.g. maternal and child mortality), there are only a few studies in the malaria domain (almost exclusively on bednets and IRS). There are almost no studies on the Burkinabé context, which is considered a severely neglected country in research terms. Furthermore, most existing studies based on the DHS datasets are limited to single, relatively simple technologies, and do not compare across several technologies.

Finally, given the lack of a standard and widely adopted methodology for the analysis of the adoption of complex health interventions, the innovative methodological approach suggested in this PhD study has the potential to overcome and address some of the difficulties of the evaluation methods used so far in the literature. This multi-disciplinary approach has helped to uncover dynamics and relationships which would not have been revealed through partial approaches such as econometric modelling or conventional qualitative studies. In particular, this approach allowed for better understanding and clearer depiction of the interrelations between general, context specific and technology specific factors. This also indirectly enabled a better understanding of the generalizability of the findings (see Section 9.3).

10.3 Policy and practice implications

The findings of this PhD study have several implications for policy and practice, which need to be taken into consideration by both policy makers and technology developers. The following sections describes them in detail.

10.3.1 Policy and practice implications for the technology developers

The qualitative system dynamics model has shown that one of the key challenges for the Target Malaria research team will be planning for the adoption of technology while simultaneously conducting the scientific and technical development. Moreover, it will be crucial for the team to manage this process without raising expectations too early at the regulatory and policy maker, as well as the general population, levels, while maintaining sufficient interest in the technology at the same time in order to avoid stalling the development and adoption process. This is magnified by the need for a societal adoption of the technology – as previously noted, adoption is not by individuals – and the generally controversial views held by many groups and individuals about GM technologies, which have fostered external resistance and scepticism towards the technology.

All these factors place emphasis on a coherent and carefully tailored communications and stakeholder engagement strategy at all levels in the health and wider adoption systems. Based on the evidence arising from the model, it will be important for this engagement strategy to emphasise the search for appropriate channels to seek local and societal approval (e.g. through local informal leaders). Further, it will be important to create trust in the technology by closing the knowledge gap, possibly through context-specific and easy-to-understand technology awareness campaigns. Joint public awareness campaigns aimed at reducing the knowledge gap currently present and fostering confidence in both the project and governmental bodies will be important. This might prove extremely challenging due to the fragmentation of the population into different cultural and language clusters. It will be necessary to find appropriate ways to communicate the

implications of the technology to the population by creating a vocabulary apt to explaining basic concepts in the local languages.

More broadly, the national government will need to shape policies which decrease the contextual barriers currently present on the ground in order to enhance social and economic resilience and hence to improve the comprehension of general malaria and technology innovations.

Another important step to foster population acceptance will be the development of a technology which does not clash with local cultural values. Despite the efforts of the Target Malaria team, the 'GM' and 'species elimination' nature of the technology may clash with the local belief systems, so an engagement and communications strategy will need to be established; this strategy needs to be jointly developed with the understanding and support of informal leaders and community-based associations.

Furthermore, given the need for a general 'system readiness', good relationships with the in-country regulatory bodies are necessary to avoid the emergence of regulatory fatigue and to support the iterative learning processes for all stakeholders. It will be crucial for the project to leave regulatory bodies the space for a clear, fact-based judgment on the technology. Collaborations with international advocacy groups engaged in the establishment of regulations and regulatory bodies might therefore be an important factor in this endeavour.

This will not be the only interaction needed with the recipient country. In fact, the interlinked, parallelised technology development and adoption process means the recipient country should be involved not only in the adoption phase but also during the development of the technology. Hence, involving governmental bodies and research institutions in the development of the technology, thus creating a local sense of ownership, is important.

Finally, it is crucial to understand that planning for adoption while doing the scientific development of a technology is an extremely complex process in itself, which requires the presence of a wide array of skillsets within the research team. These are normally not represented in purely scientific research teams; hence this

might require a degree of organisational adaptation within the team and extra resources from funding bodies. Based on the previous discussion points and policy implications it will be important to ensure that the technology development team is comprised of: a scientific research team aware of the local context peculiarities in order to deliver a tailored, context based technology, regulatory experts capable of avoiding the emergence of fatigue, risk specialists to create a tangible proof that the technology is safe and the benefits outweigh by far the risks, international and national communications and advocacy teams to gain a mixed pool of champions and to avoid the arousal of external resistance, local scientists on the ground to lead the local studies, as well as local community engagement and communications teams to develop a carefully tailored communications and engagement strategy and to support policy makers within the government in order to shape governmental programs to improve resilience factors.

10.3.2 Policy and practice implications for the Burkinabé policy makers

The research has shown that both ‘system readiness’ (including various national bodies and the health system) as well as a variety of contextual factors influence the adoption of complex health technologies, and in particular the GM mosquito technology. Hence, national governments will need to take an active role in the support of the adoption of such technologies through the implementation of a variety of policies in order to foster ‘system readiness’ and enhance resilience factors. Given the current situation on the ground, in the case of Burkina Faso these policy and practice implications will need to take a long-term perspective.

The qualitative system model and the econometric model have brought to light a series of key resilience factors which should be leveraged through specific policies. Hence, these policies should be tailored to increasing labour supply (including female labour force participation), education (both general and health specific), and the financial savings of the population. Furthermore, investments in maternal and children’s health and education need to be secured in order to achieve the aspects mentioned above. As shown through the system dynamics model, policies based on

these specific social determinants of health have the potential to increase both social and economic resilience as well as awareness factors. This, in turn, will trigger a positive cascading effect on the population's ability to better understand, judge, and eventually accept complex technologies.

Policies towards the achievement of enhanced health system readiness, and in particular of the reinforcement of the quantity of primary health facilities and the quality of the services provided would leverage the population's knowledge of health issues and improve the level of population's trust in the governmental bodies. These two factors were seen as having a positive effect on the level of trust the population places in innovative technologies and hence on the acceptance of them.

As mentioned in Section 10.3.1 these policies should be supplemented by the conceptualisation of joint public awareness campaigns with the technology development team to enhance confidence in both the project and governmental bodies.

Nevertheless, health system readiness will not be enough; the government will need to work on policies to improve the general robustness of institutional infrastructure in the country. Compared to other Sub-Saharan African countries Burkina Faso has already developed its regulatory bodies quite well for the evaluation of GM technologies, but will still need to improve their efficiency and foster the implementation of a more mature legislation with clear regulatory triggers (see Section 7.2.4) and financial resources to implement them. The system dynamics model has shown that these will play a significant role on the speed of the technology adoption, by avoiding the surge of fatigue and resistance which is driven by the complexity and length of the technology development and adoption process.

10.4 Overview of key findings

Research question	Contribution to knowledge	Policy and practice implications
Who are the key actors involved in the adoption process and what are the dynamics of the interactions between them?	The interconnection of the technology development process with the adoption of the same technology on the ground plays a major role in the speed and quality of the uptake of such technology	- Technology developers need to create a coherent and carefully tailored communications and stakeholder engagement strategy at all levels in the health and wider adoption systems; this should include also appropriate ways to communicate the implications of the technology to the population by creating a vocabulary apt to explaining basic concepts in the local languages. - Policy makers and the research team need to develop joint public awareness campaigns to reduce the knowledge gap currently present and foster confidence in both the project and governmental bodies; this is crucial as all these factors have been proven to positively impact acceptance within the population.
How does the adoption and implementation process for complex innovations that involve decisions by multiple stakeholders compare with innovations that involve individual decisions?	There is a strong interconnection between individual adoption of technology, population level acceptance and policy maker level adoption	- Create trust towards the technology by closing the knowledge gap, potentially through context-specific and understandable technology awareness campaigns - Involve governmental bodies and research institutions already in the development of the technology, thus creating an important local sense of ownership. - Create long-term policies tailored towards specific social determinants of health to leverage specific resilience factors
How do contextual factors influence the adoption process?	Importance of health system and institutional readiness on the trust vis-à-vis the technology and hence the population's propensity to accept it	- Relevant stakeholders to improve the robustness of non-health system specific institutional infrastructure (i.e. implementation of a mature legislation on GMOs with clear regulatory triggers)

How do contextual factors influence the adoption process?	Influence of context specific socio-cultural factors on adoption process, e.g. family relationships and the wider social relationships	- Emphasise the search for appropriate channels to seek local and societal approval (e.g. through local informal leaders) as crucial factor for this engagement strategy - Develop a context-specific technology which does not clash with local cultural values
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Table 18: Summary of key findings of the PhD study.

In summary, this PhD study has reinforced previous research that shows how complex the adoption of health innovation is due to the intrinsic complexity of innovations themselves, of the context, and of the adopting health systems. It has further stressed the necessity of using systems thinking as well as holistic models for the analysis of the adoption of innovative health technologies by health systems in order to avoid simplistic analyses leading to misinterpretations of the key dynamics involved in the adoption process. However, this study has also demonstrated how further layers of complexity come into the picture, for complex health technologies with an interlinked technology development and adoption processes. This has several implications for policy and practice, which have been discussed above.

10.5 Limitations of the PhD study

Like every study, it is not only important to discuss the findings of this PhD study but also to reflect on its limitations and how the effect of those was mitigated in order avoid harming the findings in a substantial way. The approach to this is outlined in the following sections.

10.5.1 General PhD study limitations

When studying complex health innovations and their adoption, unlike drugs or other well-bounded, tangible technologies, their diversity and flexibility needs to be acknowledged throughout the analysis; no standard, multi-purpose methodology is available (Drummond et al., 2007).

In most studies of complex health innovations, the external validity of the results can be questioned. It is unlikely that findings from one setting can directly inform decision making in other settings, given the necessity to take specific health and adoption systems as well as contextual features into consideration to understand the dynamics of innovation adoption. This partially also applies to this PhD study, which is examining only the specific example of the adoption of the GM mosquito technology in Burkina Faso. This country has its own unique socio-cultural, historic, and political features which might make it difficult to transfer the insights obtained in the context of this PhD study to other contexts. In order to address this issue, the original intention of the author was to perform the primary research in two contextually very different African countries, Burkina Faso and Kenya, as Target Malaria's technology was originally planned to be deployed in parallel in both countries. These countries are not only culturally very diverse, but also have different political, regulatory and public health systems. This approach would have allowed for a more differentiated overview of the differences between context and health system, as well as technology specific factors, underpinning the adoption of GM mosquitoes. Unfortunately, the partnership with the local research institution was terminated in advance, making it impossible to carry out meaningful work in Kenya. Hence, the generalizability of the findings from Burkina Faso to other low-income contexts will have to be addressed in future studies.

Similarly, it needs to be acknowledged that the technology in question is highly specific. Genetically modified mosquitoes with gene-drive for malaria elimination are not only extremely innovative and complex, but also a rather unique example of health technology. As previously seen, one of the distinguishing features is the way the technology development process is interlinked with the adoption process. Hence, translating findings from this study to other complex health technologies might not be directly possible. In order to mitigate this issue, the author also incorporated an econometric analysis of malaria prevention and elimination interventions previously deployed in Burkina Faso. This additional analysis allowed for a better overview of the technology specific factors compared to the more general factors influencing the uptake of malaria technologies in Burkina Faso.

Nevertheless, comparison of the GM mosquito technology with other complex health-related innovations in the same national context would help address this issue.

Further, the technology development process as well as the interlinked adoption process of GM mosquitoes are not only complex but also have an inherently long implementation schedule. During this PhD study it was only possible to observe a limited part of the overall process, allowing for only a partial view of the factors influencing the uptake of such a technology over time. This was partially mitigated through the interviews by asking interviewees how they envisaged the factors would change over time and throughout the different technology phases and stages. However, it would be beneficial to review the study ex-post, once the technology has been fully implemented, to gain a complete overview of the factors influencing the adoption of the technology from the start to the end of the long process of implementation and to validate how those factors change over time.

Another limitation of PhD studies involving qualitative research is the fact that the author tends to become increasingly acquainted with the context and gains more experience with the data collection methods (e.g. interviews) over time. This translates into a better quality of the later interviews compared to earlier ones. The impact of this was reduced in this study by performing short and informal interviews early in order to create a rapport with certain stakeholders (a very important aspect of the Burkinabé culture) and to gain preliminary information useful for the development of the final questionnaire. In addition, triangulation of the analysed data and discussion of the initial research findings with modelling experts, were useful for minimising this kind of researcher experience bias and allowed for improved construct validity.

More generally, during the course of the PhD study good research principles and practices were established throughout the stages of setting up and data collection, and through to the analysis of the data, in order to ensure reliable and replicable results. In the process of setting up the research the author performed a thorough review of the existing body of literature, used an acknowledged framework, developed a context-appropriate topic guide and stakeholder-cluster specific

questionnaires, established a case study database, and maintained records of all interviews and observations. During the data collection stage preliminary informal meetings were held in order to acquaint the interviewees with the topic and gain their trust. Further, the questionnaire (including prompts) was refined in the course of the data collection and evidence supporting or rejecting extreme statements or responses was sought. Data analysis of both qualitative and quantitative data was performed rigorously as specified in the methodology as well as Chapter 8 and 9.

10.5.2 Specific limitations of the econometric model

The DHS/MIS surveys used for the econometric analysis contain data collected through personal interviews with survey respondents, and include nationally representative data on fertility, family planning, maternal and child health, gender, HIV/AIDS, malaria, and nutrition covering the years 2003, 2010, and 2014. Despite frequent reviews, these types of datasets are generally subject to reporting and recall biases, a phenomenon out of the control of the author. Omission of data (i.e. births or deaths) is also one of the most serious problems of cross-sectional surveys, but this is generally held within limits in DHS studies. Further, most health information of DHS studies is based on women's reports on behalf of other family members (e.g. on children's health status). Misclassification biases are known to occur in such cases and correction of these is almost impossible due to the unknown magnitude of the bias.

Concerning the availability of the data, despite the standardised nature of DHS studies, not all the surveys on Burkina Faso contain the same level of information. In fact, the 2010 DHS survey was the only fully comprehensive DHS study; the 2003 dataset contained most of key performance indicators of the 2010 survey but only a reduced set of data for all impact evaluation measures, and the 2014 dataset comprised all malaria indicators, but only a subset of the demographic indicators. This made the comparison between the years difficult. This issue was mitigated by using the 2010 dataset as a baseline dataset and the others to compare to it whenever possible.

Further, the econometric analysis relied only on a quantitative approach, allowing only for a non-causal interpretation of the data without the possibility to establish the reasons for certain dynamics.

10.5.3 Specific limitations of the qualitative system dynamics model

In models based on qualitative data collection it is often the case that ambiguity arises from the ability of the language to support multiple meanings. This ambiguity can lead to a barrier in understanding the ‘real world’ and is hence a confounding factor. Most of the interviews for this PhD study were performed in French, which is a foreign language for both the author and most interviewees. This limitation was addressed by the use of an interpreter whenever possible and supported by verbatim transcription, but nevertheless could not be completely overcome.

Further, despite the best efforts to remain objective when explaining and analysing complex systems, humans are still affected by emotions, unconscious motivations and other non-rational factors, all playing a role in people’s judgments and behaviours. It is impossible to enforce rationalism on the side of interviewees and hence to completely avoid bias. However, the rigour of data collection, data analysis, and of the model formulation, as well as the triangulation of the analysed data and the discussion of the results with modelling experts, should have helped to minimise this unavoidable limitation and hence increase the internal validity of the study.

Limitations of qualitative system dynamics modelling in comparison to ‘full’ models have been described in Chapter 9. The purpose of the system dynamics modelling was not to quantify and hence simulate the model, which would in any case have been impossible considering the stage in the deployment of the technology, but use a systems approach to uncover relationships in the qualitative data. The rigour of data collection, analysis and of the model formulation is likely to have helped to avoid the introduction of distortion, delays, biases, and errors due to measurement errors within the model.

10.5.4 Limitations due to the realities of research environment

As with most studies coupled with ‘real-life’, ongoing projects, this PhD study was affected by the progress and necessities of Target Malaria’s project. As mentioned in Section 10.5.1 this PhD originally intended to compare the key enablers and barriers to the adoption of Target Malaria’s project in both Burkina Faso and Kenya. This was rendered impossible after the first year of PhD study due to the early termination of the collaboration between the Target Malaria and the local partnering institution. Instead, the author decided to gain a deeper understanding of the adoption process in Burkina Faso. In order to do so, the methodology was entirely revised and led to the mixed methods approach described in Chapter 4.

Further, given the sensitive and controversial nature of questions on GMOs and GM mosquitoes and the fact that Target Malaria’s project was not completely rolled out in Burkina Faso during the data collection stage of this PhD study, only interviewees deemed suitable during the interview by both the author and the local stakeholder engagement officer were asked questions on GM mosquitoes perceptions. This was mainly done in order to avoid jeopardising the Target Malaria project. In order for this limitation not to influence the results, the author adopted a purposive and snowball sampling methodology and the interview process was carried out until the saturation point in data collection also on perceptions of GMOs and GM mosquitoes was reached.

However, it should be also emphasised that the author’s involvement in the Target Malaria project was a fundamental added value to this PhD study. It allowed the author to gain an unrivalled depth and breadth of insights on factors influencing the project development and implementation process, which might have remained hidden in the interviews. Together with the range of interviewees, this increased the possibility to study the projects dynamics from a holistic 360° perspective.

10.6 Areas for future research

This PhD should be considered as a starting point for understanding the key factors and dynamics for the adoption and diffusion of self-sustaining GM mosquito strains into real-world situations, which had never been analysed before. Through the qualitative system dynamics modelling the study has not only made it possible to demonstrate the existing interrelationships between context, technology, adoption system, and health system, but also to identify the causal and qualitative relationships between those factors. Through the comparison with the existing body of literature on the adoption and diffusion of both general and malaria specific innovations as well as through the results of the econometric analysis, it was additionally possible to derive which factors are unique to the GM mosquito technology and which factors relate more to the Burkina Faso context.

A generalisation of the findings from Burkina Faso to other contexts or health systems would not be appropriate. Given that Target Malaria is working also in Mali and Uganda, it would be important to perform a similar study in those two countries, in order to understand which factors and dynamics can be deemed generalizable (if any) and which factors prove to be largely context or health system specific.

Similarly, it would be worthwhile expanding the findings from the quantitative econometric analysis with a qualitative analysis of the dynamics behind some of the established factors for the adoption of general malaria prevention and elimination technologies in Burkina Faso. This would help to shed light on some of the incongruences found in the quantitative analysis and help to provide a more concrete understanding of these factors. This would allow for a comparison of the findings with those identified in the system dynamics model.

Finally, as described in Chapter 6, both the technology development process as well as the in-country adoption process are still in an early stage. The first sterile male GM mosquito strain was imported into Burkina Faso only in November 2016, just before submission of the PhD. Hence, it would be extremely valuable to review the study ex-post once the technology has been fully adopted on the ground, in order to gain a comprehensive overview of how the factors and dynamics influencing the

adoption of the technology unfold and possibly vary over time. This would also help to validate the findings of this PhD study, and explore the evolution of key factors influencing adoption over the whole technology development and implementation cycle.

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12 Appendix

12.1 ICREC Ethics Approval



**Imperial College
London**

Imperial College Research Ethics Committee
Imperial College London
Room 5L100, 5th Floor, Lab Block
Charing Cross Hospital
Fulham Palace Road
London
W6 8RF
Tel: +44 (0)203 331 0208 Fax: +44 (0) 203 311 0203
researchethicscommittee@imperial.ac.uk

Prof Andrea Crisanti
Office 549, 5th Floor
South Kensington Campus
Sir Alexander Fleming Building
London
SW7 2AZ

26 March 2015

Dear Professor Crisanti,

Study Title: PhD research study: "Adoption and Diffusion of Novel and Complex Health Technologies in Low-Income Countries - An Example of GM Innovation for Malaria Eradication". This PhD is part of the project "Controlling the mosquito vectors of malaria with engineered endonucleases (Project Code - LBEE-P41643)".

ICREC reference: 15IC2620.

The above study was approved by your Head of Department on 26/03/15 and by the Joint Research Compliance Office on the 26/03/15.

Under the Imperial College Research Ethics Committee process, a study that has been reviewed by the Joint Research Compliance Office and Head of Division/Department (or Principal), where no significant ethical issues have been identified in the protocol or ethics application, can be approved without requiring it to go to full committee.

Documents
The documents reviewed were:

- ICREC Application form
- Risk Assessment (March 2015)
- Topic Guide (v1 March 2015)
- Consent Form (v1 March 2015)
- Local Ethics Approval (16/08/12)
- Sample Questionnaire (v1 March 2015)

Yours sincerely,



Gary Roper,
Head of Regulatory Compliance,
Imperial College London

Imperial College of Science, Technology and Medicine

12.2 CITI Training course completion report

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)		
COURSEWORK REQUIREMENTS REPORT*		
* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.		
• Name:	Valentina Cisnetto (ID: 5125892)	
• Email:	cisnetto@hsph.harvard.edu	
• Institution Affiliation:	Harvard School of Public Health (ID: 1793)	
• Institution Unit:	Global Health and Population	
• Phone:	6179434798	
• Curriculum Group:	Social & Behavioral Research Investigators	
• Course Learner Group:	Same as Curriculum Group	
• Stage:	Stage 1 - Basic Course	
• Report ID:	17488660	
• Completion Date:	10/01/2015	
• Expiration Date:	09/30/2018	
• Minimum Passing:	80	
• Reported Score:	85	
REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Belmont Report and CITI Course Introduction (ID: 1127)	09/30/15	3/3 (100%)
History and Ethical Principles - SBE (ID: 400)	10/01/15	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 491)	10/01/15	5/5 (100%)
The Federal Regulations - SBE (ID: 502)	10/01/15	4/5 (80%)
Assessing Risk - SBE (ID: 503)	10/01/15	5/5 (100%)
Informed Consent - SBE (ID: 504)	10/01/15	4/5 (80%)
Privacy and Confidentiality - SBE (ID: 505)	10/01/15	5/5 (100%)
Students in Research (ID: 1321)	10/01/15	8/10 (80%)
Conflicts of Interest in Research Involving Human Subjects (ID: 488)	10/01/15	4/5 (80%)
Harvard School of Public Health (ID: 13944)	10/01/15	No Quiz
Research with Prisoners - SBE (ID: 506)	10/01/15	2/5 (40%)
Research with Children - SBE (ID: 507)	10/01/15	4/5 (80%)
International Research - SBE (ID: 509)	10/01/15	4/5 (80%)
Vulnerable Subjects - Research Involving Workers/Employees (ID: 483)	10/01/15	4/4 (100%)
Hot Topics (ID: 487)	10/01/15	No Quiz
For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.		
CITI Program Email: citiprogram@miami.edu Phone: 305-243-7970 Web: http://www.citiprogram.org		

Appendix

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM) COURSEWORK TRANSCRIPT REPORT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

• **Name:** Valentina Cianetto (ID: 5126802)
• **Email:** vcianetto@hsph.harvard.edu
• **Institution Affiliation:** Harvard School of Public Health (ID: 1793)
• **Institution Unit:** Global Health and Population
• **Phone:** 6179434706

• **Curriculum Group:** Social & Behavioral Research Investigators
• **Course Learner Group:** Same as Curriculum Group
• **Stage:** Stage 1 - Basic Course

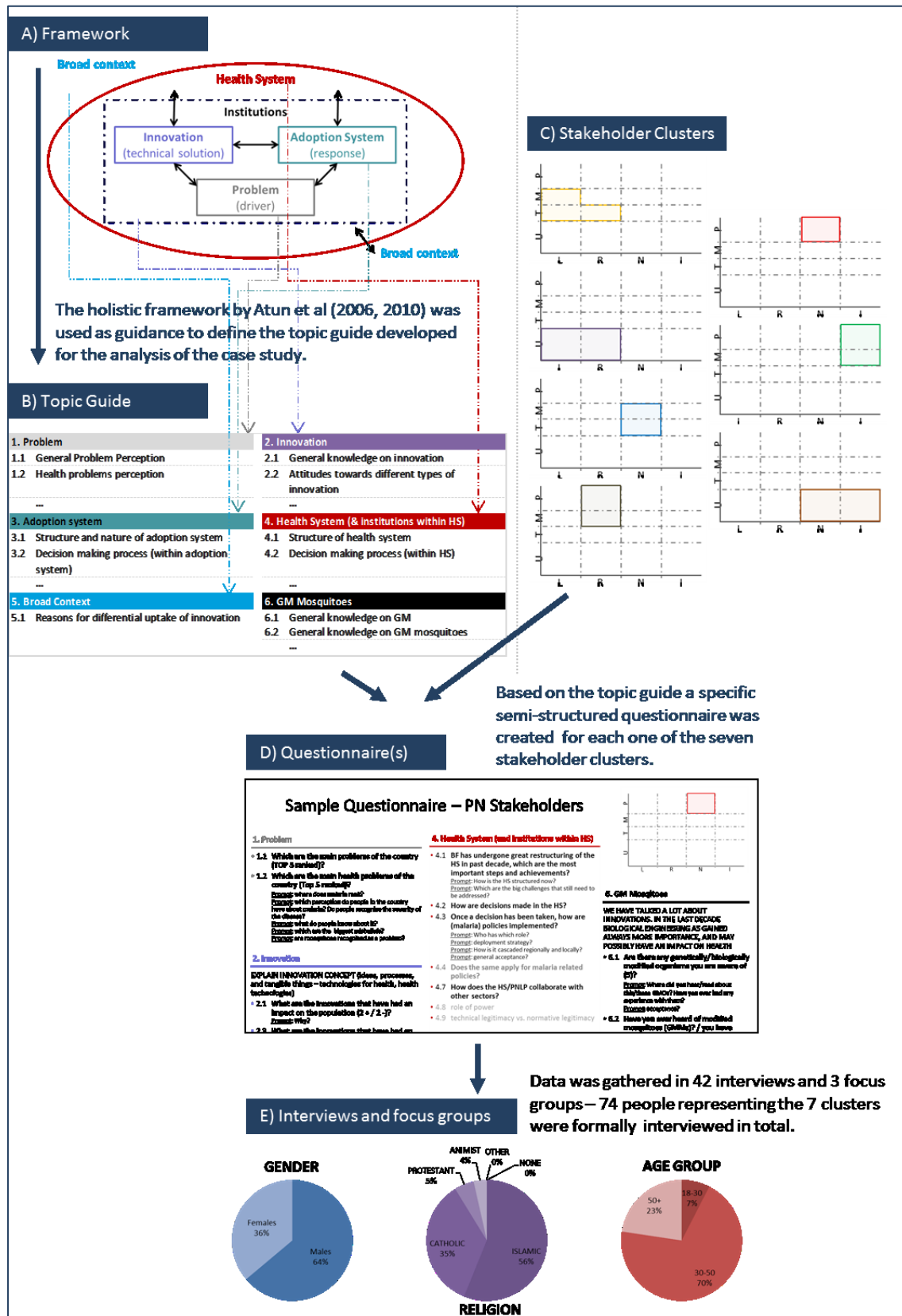
• **Report ID:** 17488960
• **Report Date:** 10/01/2015
• **Current Score**:** 85

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Students in Research (ID: 1321)	10/01/15	8/10 (80%)
Harvard School of Public Health (ID: 13044)	10/01/15	No Quiz
History and Ethical Principles - SBE (ID: 400)	10/01/15	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 401)	10/01/15	5/5 (100%)
Belmont Report and CITI Course Introduction (ID: 1127)	09/30/15	3/3 (100%)
The Federal Regulations - SBE (ID: 502)	10/01/15	4/5 (80%)
Assessing Risk - SBE (ID: 503)	10/01/15	5/5 (100%)
Informed Consent - SBE (ID: 504)	10/01/15	4/5 (80%)
Privacy and Confidentiality - SBE (ID: 505)	10/01/15	5/5 (100%)
Research with Prisoners - SBE (ID: 506)	10/01/15	2/5 (40%)
Research with Children - SBE (ID: 507)	10/01/15	4/5 (80%)
International Research - SBE (ID: 508)	10/01/15	4/5 (80%)
Vulnerable Subjects - Research Involving Workers/Employees (ID: 483)	10/01/15	4/4 (100%)
Hot Topics (ID: 487)	10/01/15	No Quiz
Conflicts of Interest in Research Involving Human Subjects (ID: 488)	10/01/15	4/5 (80%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

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Phone: 305-243-7970
Web: <http://www.citiprogram.org>

12.3 Detailed overview of the data collection and data analysis methods used for the qualitative research study – Steps A to E.



12.4 Informed Consent forms

12.4.1 Consent form for international regulatory experts

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INFORMED CONSENT FORM

This informed consent form is for participants from Burkina Faso who are invited to take part in the PhD research study, titled "Adoption and Diffusion of Novel and Complex Health Technologies in Low-Income Countries - An Example of GM innovation for Malaria Eradication".

Name of principal investigator: Valentina Cisnetto

Affiliation: Imperial College London (ICL)

Name of Supervisors: Prof Andrea Crisanti (ICL), Prof James Barlow (ICL)

Collaborators in Burkina Faso: Dr Lea Pare Toe (IRSS), Dr Abdoulaye Diabate (IRSS)

Type of study: Qualitative research interviews for PhD study

Funding Body: This PhD is funded by the project "Controlling the mosquito vectors of malaria with engineered endonucleases", which is funded by a grant from the Foundation for the National Institutes of Health (FNIH) through the Vector-Based Control of Transmission: Discovery Research (VCTR) program of the Grand Challenges in Global Health Initiative.

This Informed Consent Form has two parts:

- Information Sheet (to share information about the study with you)
- Certificate of Consent (for signatures if you choose to participate)

You will be given a copy of the full Informed Consent Form

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Part I: Information Sheet

Introduction

You have been selected as a person amongst various stakeholders to take part in a qualitative research study. Before you decide whether or not you wish to take part please read / please let me read out to you the following information sheet.

Before you decide, you can talk to anyone you feel comfortable with about the research. The same is true after the meeting today.

This consent form may contain words that you do not understand. Should this be the case, please ask me to stop as we go through and I will take time to explain.

Purpose of the research

Imperial College London (ICL) is performing a qualitative research study in collaboration with the Institut de Recherche en Sciences de la Santé du Burkina Faso (IRSS). This PhD study was launched in 2013 to support research projects in low income countries. The aim of this study is to investigate the introduction and deployment (adoption and diffusion) of complex innovative technologies in health systems.

We are especially interested understanding the adoption process of complex technologies for malaria eradication in Burkina Faso, in order to optimise the delivery of new ones. Hopefully, all this will help us design new control methods for malaria and understand how to best deploy them, so that they are adopted by the broad population and hence will make a big impact in your country.

Participant Selection

We are seeking a variety of views from individuals who represent key local and international stakeholders. We feel that your experience can contribute much to our understanding and knowledge of the local health system and the key factors to the adoption of technologies in this country. Everyone has a different perception and stake in this process, for this reason we are trying to speak to as many different people (e.g. different jobs, different backgrounds, and different experiences) as possible. We hope that you will be happy to join us in this study.

Procedures

This research will involve your participation in an interview. This interview will be guided by an experienced researcher.

We will not ask you to share personal beliefs, practices or stories unless you wish to, and you do not have to share any knowledge that you are not comfortable sharing.

The interview will take in a previously arranged place that you are comfortable with and is convenient for you. No one else but the people who take part in the discussion, the translator and the research team will be present during this interview / discussion, unless you wish so.

The meeting will be tape-recorded so that we do not miss anything important. No-one will be identified by name on the tape, though. The tape will be kept in a safe place (locked away). The recording will then be transcribed and translated into English in order to be analysed by the research team. The information recorded and transcribed is confidential, and no one else except the research team will have access to it. When the research is completed and reported, all the transcripts and tapes will be destroyed.

Duration

The interview should take approximately one hour, but this timing is flexible and mainly depends on your availability. Should there be the need, and should you wish to, we may ask for another appointment for a follow up meeting.

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Voluntary Participation and Right to Refuse or Withdraw

Your participation in this research is entirely voluntary and includes the right to withdraw. It is your choice whether to participate or not. You may also change your mind later during the interview and stop participating even if you agreed earlier. Also, even if the interview has already taken place, you can request that the information provided (or parts of it) is not used in the research study.

Refusing to participate or withdrawing (entirely or partially) from this study will have absolutely no effect on your healthcare provision or on any other parts of your life.

Benefits and Reimbursements

You will not be provided any incentive/ reimbursement to take part in the research.

There will be no direct benefit to you if you decide to take part in this study. However, your participation is likely to help us find out more about how to find a solution to the burden of malaria in Burkina Faso.

Confidentiality

The content of your answers is confidential. We will not be sharing information about you to anyone outside of the research team. The information that we collect for this research project will be kept private. Nothing will be attributed to you by name; hence any information about you will have a code on it instead of your name. Only the research team member will know what your code is and we will safely store that information.

Sharing the Results

The knowledge that we get from this research will be shared with you and your community before it is made widely available to the public. Each participant will receive a summary of the results. The results will then also be written up for publication in professional journals.

Ethical Approval

This study has been reviewed and approved by the Imperial College Research Ethics Committee (ICREC). This committee is tasked to make sure that research participants are protected from harm.

You can find more information on the committee online:

<http://www3.imperial.ac.uk/researchethicscommittee>

Who to Contact

Should you have any question at any stage of the interview please feel free to express them, we are happy to answer any questions that you might have. You can ask them now or later if they come to your mind in the future. If you wish to ask questions later, you may contact any of the following:

Valentina Cisnetto
PhD student

Imperial College London
Sir Alexander Fleming Building, desk 616
South Kensington Campus
SW7 2AZ London
United Kingdom

Mobile: 0044 7429 286631
Email: v.cisnetto@imperial.ac.uk

Dr. Léa Pare Toe
Socio-anthropologist

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01 BP 545 Bobo-Dioulasso
Burkina Faso

Phone : +226 70 75 93 61
Email : lea_toe@yahoo.com



Part II: Certificate of Consent

Title of study: Adoption and Diffusion of Novel and Complex Health Technologies in Low-Income Countries - An Example of GM innovation for Malaria Eradication

Statement by participant:

Please insert initials in box

1. I confirm that I have read the foregoing information sheet, or it has been read to me and that I understood its content ☐
2. I confirm that I have had the opportunity to ask questions and those have been answered to my satisfaction ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected ☐
4. I understand that my interview will be recorded, but that the information I provide is strictly anonymous and confidential ☐
5. A copy of this ICF has been provided me ☐
6. I agree to take part in the above study ☐

Print Name of Participant

Code of Participant

Signature

Date

Print Name of Researcher

Date

Signature

copy for participant

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Statement by participant:

Please insert initials in box

1. I confirm that I have read the foregoing information sheet, or it has been read to me and that I understood its content ☐
2. I confirm that I have had the opportunity to ask questions and those have been answered to my satisfaction ☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected ☐
4. I understand that my interview will be recorded, but that the information I provide is strictly anonymous and confidential ☐
5. A copy of this ICF has been provided me ☐
6. I agree to take part in the above study ☐

Print Name of Participant _____ Code of Participant _____ Signature _____

_____ Date

Print Name of Researcher _____ Date _____ Signature _____

copy for researcher

12.4.2 Consent form for participants in Burkina Faso

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FORMULAIRE DE CONSENTEMENT ECLAIRÉ

Ce formulaire de consentement éclairé est destiné aux participants du Burkina Faso invités à participer à l'étude de recherche de doctorat, intitulée «Adoption et diffusion de technologies de santé innovantes et complexes dans les pays à faible revenu - un exemple d'innovation GM pour l'éradication du paludisme».

Nom du chercheur principal: Valentina Cisnetto

Affiliation: Imperial College London (ICL)

Noms des superviseurs: Professeur Andrea Crisanti (ICL), Professeur James Barlow (ICL)

Collaborateurs au Burkina Faso: Dr Lea Pare Toe (IRSS), Dr Abdoulaye Diabate (IRSS)

Type d'étude: entretiens qualitatifs de recherche pour l'étude de doctorat

Organisme de financement: Cette étude de doctorat est financée par le projet « Contrôler les moustiques vecteurs du paludisme avec des endonucléases ingénierie », qui est financé par une subvention de la Fondation des Instituts Nationaux de la Santé des Etats-Unis d'Amérique (FNIH = Foundation of the National Institutes of Health of the USA) par le biais d'un programme de la Fondation Bill & Melinda Gates.

Ce formulaire de consentement éclairé comprend deux parties:

- Fiche d'information (pour partager des informations sur l'étude avec vous)
- Certificat de consentement (pour les signatures si vous décidez d'y prendre part)

Vous recevrez une copie complète du formulaire de consentement éclairé

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Email : lea_toe@yahoo.com

Partie I: Fiche d'Information

Introduction

Vous avez été sélectionné en tant que personne / groupe parmi les parties prenantes burkinabées afin de participer à une étude de recherche qualitative. Avant de décider si vous souhaitez ou non y prendre part je vous prie de bien vouloir lire/m'autoriser à vous lire la fiche d'information ci-dessous. Avant de vous décider, vous pouvez parler de la recherche à toute personne avec laquelle vous vous sentez à l'aise. Cela sera également le cas après la réunion d'aujourd'hui.

Ce formulaire de consentement peut contenir des mots que vous ne comprenez pas. Si tel est le cas, je vous prie de bien vouloir m'arrêter à ce moment là et je prendrai le temps de mieux vous expliquer.

But de la recherche

L'Imperial College London (ICL) effectue une étude de recherche qualitative en collaboration avec l'Institut de Recherche en Sciences de la Santé du Burkina Faso (IRSS). Cette étude de doctorat a été lancée en 2013 pour soutenir des projets de recherche dans les pays à faible revenu. Le but de cette étude est d'examiner l'introduction et le déploiement (adoption et diffusion) de technologies innovantes complexes dans les systèmes de santé.

Nous sommes particulièrement intéressés à la compréhension du processus d'adoption de technologies complexes pour l'éradication du paludisme au Burkina Faso, afin d'optimiser la livraison de nouvelles technologies. L'espoir est que tout ceci puisse nous aider à concevoir de nouvelles méthodes de contrôle du paludisme et à comprendre la meilleure façon de les déployer, de sorte qu'elles soient adoptées par l'ensemble de la population, ce qui aura de grandes répercussions sur l'ensemble de votre pays.

Sélection des participants

Nous cherchons une variété de points de vue de personnes qui représentent les principaux acteurs locaux. Nous pensons que votre expérience en tant que citoyen burkinabé peut grandement contribuer à notre compréhension et à notre connaissance du système de santé local de même qu'aux facteurs déterminants dans l'adoption de technologies dans ce pays. Tout le monde a une perception différente et l'enjeu est important dans ce processus, c'est pourquoi nous essayons de parler à autant de personnes différentes (par exemple, ayant des emplois différents, venant d'horizons différents, et bénéficiant de différentes expériences) que possible. Nous espérons que vous serez heureux de vous joindre à nous dans le cadre de cette étude.

Procédures

Cette recherche comprendra votre participation à un entretien / une discussion avec X autres personnes ayant des expériences similaires appelée groupe de discussion. Cet entretien / groupe de discussion sera guidé par un chercheur expérimenté, [nom]. Le traducteur, [nom du traducteur], nous aidera à traduire de la langue locale vers le français / anglais.

Nous ne vous demanderons pas de partager vos croyances personnelles, vos pratiques ou vos histoires à moins que vous ne le souhaitiez, et vous n'aurez pas à partager de choses avec lesquelles vous ne vous sentez pas à l'aise..

Cet entretien / focus de groupe se tiendra dans un endroit préalablement déterminé dans lequel vous êtes à l'aise et pratique pour vous. Personne d'autre, hormis les personnes prenant part à la discussion, le traducteur et l'équipe de recherche, ne sera présent lors de cet entretien / discussion, à moins que vous ne le souhaitiez.

La réunion sera enregistrée afin que nous ne perdions aucune partie importante. D'autre part, nul ne sera identifié par son nom sur l'enregistrement. L'enregistrement sera conservé dans un endroit sûr (enfermé). Le recodage sera ensuite transcrit et traduit en anglais afin d'être analysé par l'équipe de recherche. Les informations enregistrées et transcrites sont confidentielles, et personne d'autre, sauf l'équipe de recherche, n'y aura accès. Lorsque la recherche sera terminée et présentée, toutes les transcriptions et les enregistrements seront détruits.

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Durée

Cet entretien / focus de groupe devrait prendre approximativement une heure, mais la durée est flexible et dépend de votre disponibilité principalement. S'il y a nécessité, et si vous le souhaitez, nous pourrions fixer un autre rendez-vous pour une réunion de suivi.

Participation volontaire et droit de refus ou de rétractation

Votre participation à cette recherche est entièrement volontaire et inclut le droit de se rétracter. Le choix de participer ou non ne revient qu'à vous. Vous pouvez également changer d'avis plus tard au cours de l'entretien / groupe de discussion et cesser de participer, même si vous avez accepté auparavant. En outre, même si l'entretien / groupe de discussion a déjà eu lieu, vous pouvez demander que les renseignements fournis (ou une partie de ceux-ci) ne figurent pas dans l'étude de recherche.

Le refus de participation ou la rétractation (entière ou partielle) vis à vis de cette étude n'aura absolument aucun effet sur votre prestation de soins de santé ou sur d'autres aspects de votre vie.

Aides et remboursements

Aucune incitation / remboursement ne sera proposé pour participer à cette recherche.

Vous ne bénéficierez d'aucun avantage direct si vous décidez de prendre part à cette étude. Cependant, votre participation est susceptible de nous aider à en savoir plus sur la façon de trouver une solution au fardeau que constitue le paludisme au sein de votre communauté et dans votre pays.

Confidentialité

Le contenu de vos réponses est confidentiel. Nous ne partagerons les informations vous concernant avec personne en dehors de l'équipe de recherche. Les informations que nous recueillerons pour ce projet de recherche resteront strictement privées. Il n'y aura rien d'intitulé à votre nom; donc chaque information vous concernant aura un code à la place de votre nom. Seul le membre de l'équipe de recherche connaîtra votre code et nous stockerons cette information en toute sécurité.

Partage des résultats

Les connaissances que nous obtiendrons de cette recherche seront tout d'abord partagées avec vous et votre communauté avant d'être dévoilées publiquement. Chaque participant recevra un résumé des résultats. Ces résultats seront ensuite également publiés dans des journaux spécialisés.

Approbation éthique

Cette étude a été examinée et approuvée par le Comité Imperial College éthique de la recherche (ICREC). Ce comité est chargé de s'assurer que les participants de cette recherche soient protégés contre les atteintes. Vous pouvez trouver davantage d'informations sur le comité en ligne:

<http://www3.imperial.ac.uk/researchethicscommittee>

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Qui contacter

Si vous avez des questions à tout moment de l'entretien, nous vous invitons à les exprimer ; nous serions d'ailleurs très heureux de répondre à toutes les questions que vous pourriez avoir. Vous pouvez nous les poser dès maintenant ou plus tard si elles vous viennent à l'esprit par la suite. Si vous souhaitez poser des questions plus tard, vous pourrez vous mettre en contact avec l'une des personnes suivantes:

Valentina Cisnetto
PhD student

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United Kingdom

Mobile: 0044 7429 286631
Email: v.cisnetto@imperial.ac.uk

Nourou Barry
Doctorant

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Partie II: Certificat de Consentement

Titre de l'étude: Adoption et diffusion de technologies de la santé innovantes et complexes dans les pays à faible revenu - un exemple d'innovation GM pour l'éradication du paludisme.

Déclaration par le participant:

Veuillez insérer vos initiales dans la case

1. Je confirme avoir lu la fiche de renseignements ci-dessus, ou elle m'a été lue, et j'ai compris son contenu ☐
2. Je confirme avoir eu l'occasion de poser des questions et les réponses à celles-ci ont été satisfaisantes ☐
3. Je comprends que ma participation est volontaire et que je suis libre de me rétracter à tout moment, sans donner de raison, sans que mes droits légaux ne soient affectés ☐
4. Je comprends que mon entretien sera enregistré, mais les informations que je fournis sont strictement anonymes et confidentielles ☐
5. Une copie de ce formulaire m'a été remise ☐
6. Je suis d'accord pour prendre part à l'étude ci-dessus ☐

Nom du participant

Code du Participant

Signature

Date

Nom du chercheur

Date

Signature

copie du participant

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Déclaration par le participant:

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1. Je confirme avoir lu la fiche de renseignements ci-dessus, ou elle m'a été lue, et j'ai compris son contenu ☐
2. Je confirme avoir eu l'occasion de poser des questions et les réponses à celles-ci ont été satisfaisantes ☐
3. Je comprends que ma participation est volontaire et que je suis libre de me rétracter à tout moment, sans donner de raison, sans que mes droits légaux ne soient affectés ☐
4. Je comprends que mon entretien sera enregistré, mais les informations que je fournis sont strictement anonymes et confidentielles ☐
5. Une copie de ce formulaire m'a été remise ☐
6. Je suis d'accord pour prendre part à l'étude ci-dessus ☐

Nom du participant

Code du Participant

Signature

Date

Nom du chercheur

Date

Signature

copie du chercheur

12.5 Interview questionnaire guidelines

Imperial College
London

5 Questionnaire Design

1. Problem

- What is the problem?
- How is the problem defined?
- How is the problem measured?
- How is the problem addressed?

2. Innovation

- What is the innovation?
- How is the innovation defined?
- How is the innovation measured?
- How is the innovation addressed?

3. Adoption System

- What is the adoption system?
- How is the adoption system defined?
- How is the adoption system measured?
- How is the adoption system addressed?

4. Health System (and institutions within HS)

- What is the health system?
- How is the health system defined?
- How is the health system measured?
- How is the health system addressed?

5. Broad Context

- What is the broad context?
- How is the broad context defined?
- How is the broad context measured?
- How is the broad context addressed?

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5 Questionnaire – Template for filling in questions

1. Problem

- 1.1 general problem perception
- 1.2 health problems perception
- 1.3 general knowledge & perceptions on malaria
- prevention / treatment of malaria
- 1.4 magnitude of the problem: ranking of malaria within health problems and general problems

2. Innovation

- 2.1 general knowledge on innovation
- 2.2 attitudes towards different types of innovation
- 2.3 general knowledge on innovations for malaria
- 2.4 attitudes towards innovations for malaria
- 2.5 diffusion process of malaria innovation (intervention path)

6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?

Prompt: Where did you hear/read about this/these GMOs?

Prompt: Which information sources would you use to gain more information on GMOs?

- 6.2 Have you ever heard of GM mosquitoes (GMMs)?

Prompt: Where did you hear/read about GMMs?

- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?

Prompt: Why?

- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?

Prompt: Under which circumstances would you accept the release of GMMs?

4. Health System (and institutions within HS)

- 4.1 structure of health system
- 4.2 decision making process (within HS)
- 4.3 policy implementation strategy (within HS)
- 4.4 policy implementation strategy for malaria (within HS)
- 4.5 deployment strategy of malaria intervention (within HS)
- 4.6 general acceptance and attitude towards decisions taken
- 4.7 links and relations to other systems / levels
- 4.8 role of power
- 4.9 technical legitimacy vs. normative legitimacy

3. Adoption System

- 3.1 structure and nature of adoption system
- 3.2 decision making process (within adoption system)
- 3.3 decision implementation strategy (within adoption system)
- 3.4 links and relations to other systems (e.g. HS) / levels
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.6 role of power
- 3.7 legitimacy in the adoption system

5. Broad Context

- 5.1 reasons for differential uptake of innovation
- 5.2 ...

5 Questionnaire – UL / UR Stakeholders

1. Problem

- 1.1 Which are the main problems you encounter in daily life (3)?
- 1.2 Which are the main health problems your village encounters in daily life (3)?
- 1.3 You (did not) mentioned malaria, what do you know about it?
 Prompt: How do you prevent and treat malaria in your village?
 Prompt: Who is most affected by malaria and why?
 Prompt: Role of mosquitoes?
 Prompt: Where would you rank it amongst the other problems mentioned?

3. Adoption System

- 3.1 How is your village organised?
 Prompt: Who has which function / a leading role?
 Prompt: Who are the influencers?
- 3.2 How are decisions made?
- 3.3 Once a decision has been taken, how is it implemented?
 Prompt: legitimacy and political economy
- 3.4 How are national / regional decisions implemented locally?
 Prompt: decisions taken in HS
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.7 legitimacy in the adoption system

5. Broad Context

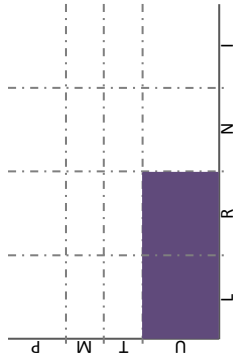
- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?
 Prompt: who in the village can influence those decisions?

2. Innovation

- 2.1 What are the innovations that have had an impact on the problems mentioned before (2 positive / 2 negative)?
 Prompt: Why?
 Prompt: How were they diffused in the village?
- 2.2 How did people react when they were confronted with it for the first time?
 Prompt: What convinced them to uptake it? Why were they against it?
- 2.3 general knowledge on innovations for malaria
- 2.4 attitudes towards innovations for malaria
- 2.5 diffusion process of malaria innovation (intervention path)

4. Health System (and institutions within HS)

- 4.1 structure of health system
- 4.2 decision making process (within HS)
- 4.3 policy implementation strategy (within HS)
- 4.4 policy implementation strategy for malaria (within HS)
- 4.5 Once the HS takes a decision, how is it rolled out in the village?
- 4.6 How is it accepted by the villagers?
- 4.7 links and relations to other systems / levels
- 4.8 role of power
- 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
 Prompt: Where did you hear/read about this/these GMOs?
 Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
 Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
 Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
 Prompt: Under which circumstances would you accept the release of GMMs?

5 Questionnaire – UN / UI Stakeholders

1. Problem

- 1.1 Which are the main problems of the country (5)?
- 1.2 Which are the main health problems of the country(3)?
- 1.3 You (did not) mentioned malaria, what do you know about it?
 Prompt: How do you prevent and treat malaria in your village?
 Prompt: Who is most affected by malaria and why?
 Prompt: Are mosquitoes recognised as a problem?
 Prompt: where would you rank it amongst the other problems mentioned?

3. Adoption System

- 3.1 How is the Burkinabe society organised?
 Prompt: Who has which function / a leading role?
 Prompt: Who are the influencers?
- 3.2 How are decisions made?
- 3.3 Once a decision has been taken, how is it implemented?
 Prompt: legitimacy and political economy
- 3.4 How are national / regional decisions implemented locally?
 Prompt: decisions taken in HS
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels

5. Broad Context

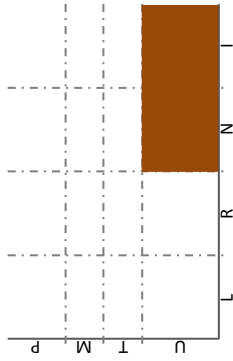
- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?

2. Innovation

- 2.1 What are the innovations that have had an impact on the problems mentioned before (2 positive / 2 negative)?
 Prompt: Why?
 Prompt: How were they implemented?
 Prompt: Who was behind these innovations?
- 2.2 How did people react when they were confronted with it for the first time?
 Prompt: What convinced them to uptake it? Why were they against it?
 Prompt: Which were the strategies to locally inform people on the issues related to the technology?
 • 2.3 general knowledge on innovations for malaria
 • 2.4 attitudes towards innovations for malaria
 • 2.5 diffusion process of malaria innovation (intervention path)

4. Health System (and institutions within HS)

- 4.1 structure of health system
- 4.2 decision making process (within HS)
- 4.3 policy implementation strategy (within HS)
- 4.4 policy implementation strategy for malaria (within HS)
- 4.5 deployment strategy of malaria intervention (within HS)
- 4.6 Generally, how are decisions taken in the HS accepted?
- 4.7 How does your sector collaborate with the HS?
 Prompt: How do decisions taken in HS reflect on your sector?
 • 4.8 role of power
 • 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
 Prompt: Where did you hear/read about this/these GMOs?
 Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
 Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
 Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
 Prompt: Under which circumstances would you accept the release of GMMs?

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5 Questionnaire – TL / TR / LM Stakeholders

1. Problem

- 1.1 Which are the main problems you encounter in day to day life (3)?
- 1.2 Which are the main local / regional health problems (5)?
- 1.3 You (did not) mentioned malaria, what do you know about it?
Prompt: How do people prevent it?
Prompt: Who is most affected by malaria and why?
Prompt: Are mosquitoes recognised as a problem?
- 1.4 Where would you rank it amongst the other problems mentioned?
Prompt: Do people recognise the severity of the disease?

3. Adoption System

- 3.1 structure and nature of adoption system
- 3.2 decision making process (within adoption system)
- 3.3 decision implementation strategy (within adoption system)
- 3.4 links and relations to other systems (e.g. HS) / levels
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.6 role of power
- 3.7 legitimacy in the adoption system

5. Broad Context

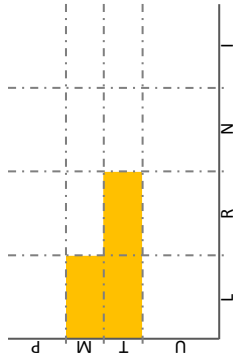
- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?

2. Innovation

- 2.1 What are the innovations that have had an impact on the problems mentioned before (2 positive / 2 negative)?
Prompt: Why?
Prompt: How were they disseminated?
- 2.2 How did people react when they were confronted with it for the first time?
Prompt: What convinced them to uptake it? Why were they against it?
- 2.3 What are the innovations that have had an impact on malaria (positive / negative)?
Prompt: Why?
- 2.4 What was the general attitudes towards those malaria innovations?
- 2.5 How were they distributed to people?

4. Health System (and institutions within HS)

- 4.1 How does the local HS work?
- 4.2 How are decisions taken in the local HS?
- 4.3 Once a decision to implement a health technology has been taken, how is it implemented locally?
Prompt: which are the strategies to locally inform people on them?
- 4.4 Does the same apply for malaria technologies?
- 4.6 How are those decisions generally accepted?
- 4.7 Do you collaborate with institutions outside of the HS / non-healthcare sectors ?
- 4.8 role of power
- 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
Prompt: Where did you hear/read about this/these GMOs?
Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
Prompt: Under which circumstances would you accept the release of GMMs?

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5 Questionnaire – MR / PR Stakeholders

1. Problem

- 1.1 Which are the main problems of the country (3)?
- 1.2 Which are the main health problems of the country(5)?
Prompt: which perception do people in the country have about them?
- 1.3 You (did not) mentioned malaria, what do you know about it?
Prompt: How do people prevent it?
Prompt: Who is most affected by malaria and why?
Prompt: Are mosquitoes recognised as a problem?
Prompt: Where would you/ where do people rank it amongst the other problems mentioned?

3. Adoption System

- 3.1 structure and nature of adoption system
- 3.2 decision making process (within adoption system)
- 3.3 decision implementation strategy (within adoption system)
- 3.4 links and relations to other systems (e.g. HS) / levels
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.6 role of power
- 3.7 legitimacy in the adoption system

5. Broad Context

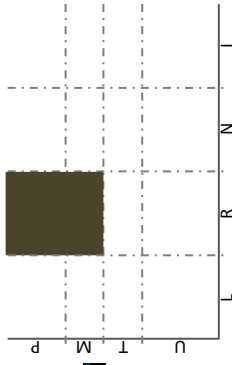
- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?

2. Innovation

- 2.1 What are the innovations that have had an impact on the health problems mentioned before (2 positive / 2 negative)?
Prompt: Why?
Prompt: How were they disseminated?
- 2.2 How did people react when they were confronted with it for the first time?
Prompt: What convinced them to uptake it? Why were they against it?
- 2.3 What are the innovations that have had an impact on malaria (positive / negative)?
Prompt: Why?
- 2.4 What was the general attitudes towards those malaria innovations?
- 2.5 How were they distributed to people?

4. Health System (and institutions within HS)

- 4.1 How does the regional HS work?
- 4.2 How are decisions taken in the regional HS?
- 4.3 Once a decision to implement a health technology has been taken nationally / regionally, how is it implemented regionally / locally?
Prompt: which are the strategies to locally inform people on them?
- 4.4 Does the same apply for malaria technologies?
- 4.6 How are those decisions generally accepted?
- 4.7 Do you collaborate with institutions outside of the HS / non-healthcare sectors ?
role of power
- 4.8
- 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
Prompt: Where did you hear/read about this/these GMOs?
Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
Prompt: Under which circumstances would you accept the release of GMMs?

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5 Questionnaire – PN Stakeholders

1. Problem

- 1.1 Which are the main problems of the country (5)?
- 1.2 Which are the main health problems of the country(3)?
Prompt: which perception do people in the country have about them?
- 1.3 general knowledge & perceptions on malaria prevention / treatment of malaria
- 1.4 magnitude of the problem: ranking of malaria within health problems and general problems

3. Adoption System

- 3.1 structure and nature of adoption system
- 3.2 decision making process (within adoption system)
- 3.3 decision implementation strategy (within adoption system)
- 3.4 links and relations to other systems (e.g. HS) / levels
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.6 role of power
- 3.7 legitimacy in the adoption system

5. Broad Context

- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?

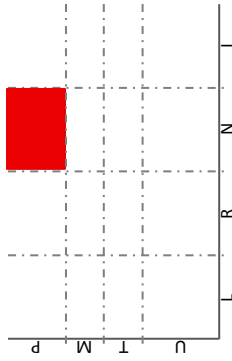
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2. Innovation

- 2.1 What are the innovations that have had an impact on the population (2 + / 2 -)?
Prompt: Why?
- 2.3 What are the innovations that have had an impact on health (5+ / 5 -)?
Prompt: Why?
Prompt: How were they disseminated?
- 2.2 How did people react when they were confronted with them for the first time?
Prompt: what convinced them to uptake it? Why were they against it?
Prompt: What was the general attitudes towards those malaria innovations?
- 2.5 How were they distributed to people?

4. Health System (and institutions within HS)

- 4.1 BF has undergone great restructuring of the HS in past decade, which are the most important steps and achievements?
Prompt: How is the HS structured now?
Prompt: Which are the big challenges that still need to be addressed?
- 4.2 How are decisions made in the HS?
- 4.3 Once a decision has been taken, how are policies implemented?
Prompt: Who has which role?
Prompt: How is it cascaded regionally and locally?
- 4.4 Does the same apply for malaria related policies?
- 4.5 deployment strategy of malaria intervention
- 4.6 general acceptance and attitude towards decisions taken
- 4.7 How does the HS collaborate with other sectors?
- 4.8 role of power
- 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
Prompt: Where did you hear/read about this/these GMOs?
Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
Prompt: Under which circumstances would you accept the release of GMMs?

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5 Questionnaire – TN / MN Stakeholders

1. Problem

- 1.1 Which are the main problems of the country (3)?
- 1.2 Which are the main health problems of the country(5)?
Prompt: which perception do people in the country have about them?
- 1.3 You (did not) mentioned malaria, what do you know about it?
Prompt: How do people prevent it?
Prompt: Who is most affected by malaria and why?
Prompt: Are mosquitoes recognised as a problem?
Prompt: Where would you/ where do people rank it amongst the other problems mentioned?

3. Adoption System

- 3.1 structure and nature of adoption system
- 3.2 decision making process (within adoption system)
- 3.3 decision implementation strategy (within adoption system)
- 3.4 links and relations to other systems (e.g. HS) / levels
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.6 role of power
- 3.7 legitimacy in the adoption system

5. Broad Context

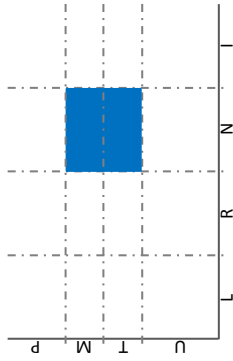
- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?

2. Innovation

- 2.1 What are the innovations that have had an impact on the population (2 + / 2 -)?
Prompt: Why?
- 2.3 What are the innovations that have had an impact on health (5+ / 5 -)?
Prompt: Why?
Prompt: How were they disseminated?
Prompt: lessons learned?
- 2.2 How did people react when they were confronted with them for the first time?
Prompt: what convinced them to uptake it? Why were they against it?
Prompt: What was the general attitudes towards those malaria innovations?
- 2.5 How were they distributed to people?

4. Health System (and institutions within HS)

- 4.1 How does the national HS work?
- 4.2 How are decisions taken in the national HS?
Prompt: Coordination with other national strategies and interventions
- 4.3 Once a decision to implement a health technology has been taken nationally, how is it implemented regionally / locally?
Prompt: which are the strategies to locally inform people on them?
Prompt: How do you work with policy makers and regional local HS actors?
- 4.4 Does the same apply for malaria technologies?
- 4.6 How are those decisions generally accepted?
- 4.7 Do you collaborate with institutions outside of the HS / non-healthcare sectors?
- 4.8 role of power
- 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
Prompt: Where did you hear/read about this/these GMOs?
Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
Prompt: Under which circumstances would you accept the release of GMMs?

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5 Questionnaire – MI / PI Stakeholders

1. Problem

- 1.1 Which are the main problems of the country (3)?
- 1.2 Which are the main health problems of the country(5)?
Prompt: which perception do people in the country have about them?
- 1.3 You (did not) mentioned malaria, what do you know about it?
Prompt: How do people prevent it?
Prompt: Who is most affected by malaria and why?
Prompt: Are mosquitoes recognised as a problem?
Prompt: Where would you/ where do people rank it amongst the other problems mentioned?

3. Adoption System

- 3.1 structure and nature of adoption system
- 3.2 decision making process (within adoption system)
- 3.3 decision implementation strategy (within adoption system)
- 3.4 links and relations to other systems (e.g. HS) / levels
- 3.5 general acceptance and attitude towards decisions taken by other systems / at different levels
- 3.6 role of power
- 3.7 legitimacy in the adoption system

5. Broad Context

- 5.1 Which are in your view the factors important for people when they are confronted with a new technology?

2. Innovation

- 2.1 What are the innovations that have had an impact on the population (2 + / 2 -)?
Prompt: Why?
- 2.3 What are the innovations that have had an impact on health (5+ / 5 -)?
Prompt: Why?
Prompt: How were they disseminated?
Prompt: lessons learned?
- 2.2 How did people react when they were confronted with them for the first time?
Prompt: what convinced them to uptake it? Why were they against it?
Prompt: What was the general attitudes towards those malaria innovations?
- 2.5 How were they distributed to people?

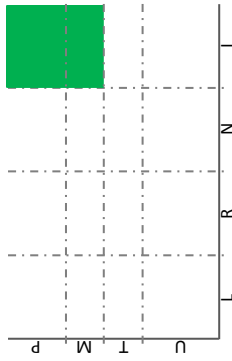
4. Health System (and institutions within HS)

- 4.1 BF has undergone great restructuring of the HS in past decade, which are the most important steps and achievements?
Prompt: How is the HS structured now?
Prompt: Which are the big challenges that still need to be addressed?
- 4.2 decision making process (within HS)
- 4.3 Once a decision has been taken, how are policies implemented?
Prompt: Who has which role?
Prompt: How is it cascaded regionally and locally?
- 4.6 How are those decisions generally accepted?
- 4.7 How does the international health agenda of your organisation tie in with the country one (general and malaria)?
Prompt: How is decision taking cascaded to national strategies?

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N^o 4.8 role of power

• 4.9 technical legitimacy vs. normative legitimacy



6. GM Mosquitoes

- 6.1 Which genetically modified organisms (GMOs) do you know (5)?
Prompt: Where did you hear/read about this/these GMOs?
Prompt: Which information sources would you use to gain more information on GMOs?
- 6.2 Have you ever heard of GM mosquitoes (GMMs)?
Prompt: Where did you hear/read about GMMs?
- 6.3 Do you think that GMMs are a possible and feasible innovation against malaria?
Prompt: Why?
- 6.4 Which are the factors important to you that could change your mind on the adoption of the technology?
Prompt: Under which circumstances would you accept the release of GMMs?

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12.6 Quotes from interviews – original quotes and translations

#	Role	Original quote	Translation (English)
1	Retired health professional at regional user level	Il y a aussi le problème d'accès des enfants à l'école. Ça devient de plus en plus cher, les petits arrêtent à un niveau intermédiaire à cause des moyens. BF-BD-RU-AKA-TA	There is also the problem of enrolling children to school. This becomes more and more expensive. Most little ones stop at middle school level due to lack of funds. BF-BD-RU-AKA-TA
2	Religious leader from a rural village at local user level	mais surtout, l'essentiel, la plus grosse: la pauvreté. [...] En tant qu'Imam les gens viennent à lui avec beaucoup de problèmes, le plus grand est la pauvreté. Sur 10 personnes, 8 personnes viendront pour la pauvreté. BF-VK-LU-ANA-YE	But above all, the essential, the biggest issue: poverty [...]. As far as the Imam is concerned, people are seeing him because of a range of problems with poverty being the biggest issue. Out of 10 people, 8 are coming because of poverty. BF-VK-LU-ANA-YE
3	General Secretary of a network of NGO at national technical level	De façon globale, c'est la pauvreté qui est le facteur visible et clair, accentuée par la non-scolarisation et le cycle de pauvreté s'agrandit. 39 Interview A B C D	Globally speaking, poverty is the most visible and clear factor, which is further accentuated by low enrolment rates. And so the poverty cycle is increasing. 39 Interview A B C D
4	Member of an all-women focus group from a rural village at local user level	Maux de pieds, Hypertension, Diarrhée, Ulcère d'estomac... The fact of not being able to work. Focus Group 01	Sore feet, hypertension, diarrhoea, stomach ulcers... the fact of not being able to work. Focus Group 01
5	Religious leader from a rural village at local user level	Le troisième grand problème ici c'est le travail, l'activité productive. BF-BA-LU-DOU-SA	The third big problem here is labour, the production activity. BF-BA-LU-DOU-SA

Appendix

6	General Secretary of a network of NGOs at national technical level	Il y a un problème de pauvreté et un problème d'affirmation de soi. Même quand vous avez des idées, vous n'avez pas l'opportunité de les exploiter, c'est encouragé par l'éducation mais selon les provinces, dans le Centre-nord par exemple, les gens ne vont pas à l'école et quand ils y vont, ce sont les garçons, les filles ne vont pas à l'école, il y a même des villages où il est décrété que les filles n'iront pas à l'école. Quand elles y vont, elles reviennent à partir de la 5ème ou 4ème avec une grossesse, donc on préfère les garder, les marier au village et elle n'ira pas à l'école. 39 Interview A B C D	There is a problem of poverty and a problem of assertiveness. Even if you have ideas you do not have the chance to pursue them. It would be encouraged by the educational system but depending on the provinces, in the Center-North for example, people don't go to school. And even if they go, it's for boys only; girls don't go to school, there are even villages which have decreed that girls must not go to school. And if they go after all, they come back pregnant from the 5th or 4th grade onwards. Thus, it is preferred to keep them at home, to wed them within the village and not send them to school. 39 Interview A B C D
7	General Secretary of a governmental administration at regional user level	Les problèmes de base, les besoins prioritaires comme l'éducation, la santé, l'assainissement, la voirie. Ceux-ci ce sont les problèmes principaux comment-ca. Santé, éducation, le haute, voilà. BF-BD-RU-SSA-SA	The basic problems, the priority needs are education, healthcare, sanitation, road infrastructure. Those are the main problems: health, education, roads...there you go. BF-BD-RU-SSA-SA

Appendix

8	Retired mayor of a mid-sized village at local user level	En milieu rural particulièrement, c'est la pauvreté de la population, la non information, l'analphabétisme qui va créer beaucoup de problème et qui jouent beaucoup sur la compréhension. Grosso modo c'est l'analphabétisme... Les gens ne sont pas informé. Les gens ne savent pas ou ne comprennent pas ce qu'on leur propose. Dans le domaine de la santé, le problème est le même. BF-BD-LU-QUE-TR	Especially in the rural environment, it will be [issues like] the poverty of the population, the lack of information, illiteracy which will create problems; those are linked to a great extend to comprehension. Grosso modo, it's the illiteracy... people are not informed. The people do not know or don't understand what is proposed to them. In the healthcare sector, the problem is the same. BF-BD-LU-QUE-TR
9	Project manager of a national NGO at national managerial level	Il y a beaucoup des problèmes. La pauvreté d'accès aux services sociaux de base, de santé, d'éducation, d'emploi pour les jeunes et les femmes. Problèmes aussi le facteur de productions quand vous allez dans le monde rural, l'accès aux emprunts, aux crédits agricoles, aux appuis pour pouvoir développer leur moyen de subsistance et gérer leurs revenus et faire face à leurs autres besoins. BF-OA-NM-TRE-TI	There are a lot of problems: poverty, access to basic social services, healthcare, education, employment for young people and women. Problems are also production output - if you go to rural areas - and difficult access to borrowing, agricultural loans as well as to support to be able to develop their livelihood and manage their revenues in order to confront their needs. BF-OA-NM-TRE-TI
10	Executive director within the Ministry of Health at national policy maker level	Le document de politique de santé a identifié les principaux problèmes de santé au Burkina se résumant à la forte mortalité maternelle et infantile. [...] Et les maladies les plus ciblées sont le paludisme, la tuberculose, le VIH et la promotion de la santé de la reproduction. BF-OA-NP-NNE-VA	The health policy document has identified the main healthcare problems in Burkina Faso which resulted from the high maternal and infant mortality. [...] And the most addressed diseases are malaria, tuberculosis, HIV and the promotion of reproductive health. BF-OA-NP-NNE-VA

Appendix

11	Representative of a civil society group at regional user level	La santé est un problème prioritaire de nos populations mais quand on dit santé il faut comprendre ce que on met dans la santé, selon l’OMS, cela repose sur un état de bien-être complet, non l’absence de maladie mais le bien-être physique, moral, matériel. Si on dit que le premier problème c’est la santé on doit le voir d’une façon générale. BF-BD-RU-ANA-BE	Health is a priority issue for our populations. But if we say health it is important to understand what is subsumed under health. According to the WHO, this is based on a state of complete well-being; not on the absence of disease but the physical, moral and material well-being. So if we say that health is the main problem we need to look at this in a general way. BF-BD-RU-ANA-BE
12	Communication officer of a national NGO at national managerial level	Il n’y a pas de réflexe de se rendre dans une formation sanitaire quand on est malade car on anticipe les dépenses auxquelles on ne pourrait pas faire face. Le réflexe c’est de gérer son mal comment on peut, ça va créer beaucoup de retard à la présentation des formations sanitaires. Lorsque les gens se présentent il est déjà trop tard. Tout est un problème ici. BF-OA-NM-RRE-OU	There is no impetus to visit a healthcare facility if one is ill because one expects costs that could not be covered. The impetus would be to manage one's illness as good as possible which will lead to a significant delay before visiting the healthcare facilities. When the people get there it is already too late. Everything is a problem here. BF-OA-NM-RRE-OU
13	Regional director within the Ministry of Health at regional managerial level	[...] nous avons toujours eu des problèmes car les gens viennent mais tardivement ce qui suppose beaucoup d’automédication ou des consultations chez le tradipraticien. BF-BD-RM-ENT-ME	[...] we have always had problems because people arrive [at the facilities] but too late which means a lot of [prior] self-medication or consultations with a traditional healer. BF-BD-RM-ENT-ME

Appendix

14	Member of civil society association at regional user level	Les accès aux services de santé, pas seulement pour l'accès physique mais aussi aux dépenses de santé car il n'y a pas de système de couverture sociale ou d'assurance maladie pour faire face aux coûts des services de santé, ainsi beaucoup préfèrent rester en marge.	Access to healthcare services [is one of the big challenges], not only concerning the physical access but also with regards to healthcare costs as there are no social insurance health insurance schemes to cover those costs; thus, may prefer to remain on the side-lines.
15	Executive director within the Ministry of Health at national policy maker level	De même, les problèmes liés aux capacités de prises en charge du système de santé, la couverture, la qualité et l'accessibilité financière des populations par rapport aux services de santé. BF-OA-NP-NNE-VA	Similarly, problems are linked to management capacities of the health system, its coverage, quality and financial accessibility of healthcare services for the population. BF-OA-NP-NNE-VA
16	Representative of a civil society group at regional user level	Par exemple, on peut avoir l'accès géographique aux centre de santé mais certaines personnes vivant en face du centre de santé n'y vont pas, il y a des gens qui ont l'accès financière mais ne vont pas et ils sont réticents, c'est un problème surtout culturel, la façon de communiquer qui jouent un grand rôle, ainsi, les gens peuvent être à des distances acceptables mais ne s'y rendent pas. BF-BD-RU-ANA-BE	For example, it is possible to have geographical access to healthcare centres but a number of people living in the proximity of those centres won't go there; there are people with financial access but they won't go and are reluctant. It is mainly a cultural problem; the way of communicating plays a big role. So people can be within acceptable distances but won't go there. BF-BD-RU-ANA-BE

Appendix

17	Member of an all-women focus group from a rural village at local user level	She added that some say that if doctors flattered them to get vaccinated, that shows it's because they want to inject diseases in their bodies so that they go and pay more money at the CSPA. The doctors would get them ill so that they would go to the CSPA and pay a lot of money there. That is the idea of some of them. Focus group 01	She added that some say that if doctors flattered them to get vaccinated, that shows it's because they want to inject diseases in their bodies so that they go and pay more money at the CSPA. The doctors would get them ill so that they would go to the CSPA and pay a lot of money there. That is the idea of some of them. Focus group 01
18	Member of an all-women focus group from a rural village at local user level	She said that if someone comes and ask to vaccinate them, and they had never heard about it, they would refuse it because they wouldn't know what the person would be injecting in their body. They would even hide their children... Focus group 01	She said that if someone comes and ask to vaccinate them, and they had never heard about it, they would refuse it because they wouldn't know what the person would be injecting in their body. They would even hide their children... Focus group 01
19	Founder and leader of national NGO at national managerial level	Le problème qu'on a aujourd'hui ici sur l'application des mesures est celle du leadership du niveau central. Le pouvoir du niveau central est très faible, les DRS, MCD pensent pouvoir faire ce qu'ils veulent malgré les décisions du niveau centrale et ils le font sans sanctions. Le sens de la redevabilité n'existe pratiquement plus malheureusement. BF-OA-NM-MON-KA	The problem we have today with the implementation of the measures is the leadership at the central level. The power of the central level is very low; the DRS and MCD think they can do what they want regardless of the decisions of the central level. And they do so without sanctions. Unfortunately, there is virtually no sense of accountability. BF-OA-NM-MON-KA

Appendix

20	Retired mayor of a mid-sized village at local user level	Nous impliquons les responsables locaux, les chefs du village, les adjoints, les envoyés, le cvd du village, les chefs coutumiers. Alors, les gens viennent car eux participent. On a besoin de leur aide technique. Les gens dit: il y a le coutumiers... les gens viennent. BF-BD-LU-QUE-TR	We involve the local leaders: village chiefs, deputies, envoys, the CVD of the village, as well as the 'leader of tradition'. So people come because they participate. We need their technical help. The people say: 'there are the traditional leaders'... and then they come. BF-BD-LU-QUE-TR
21	Retired health professional at regional user level	Dans chaque village, il y a les chefs de communautés, musulmane ou catholique, qui participent à la communication des techniques (ministère de la santé). BF-BD-RU-AKA-TA	In every village, there are the leaders of the communities, Muslim or Catholic, who participate in the communication of techniques (Ministry of Health). BF-BD-RU-AKA-TA
22	Retired health professional at regional user level	Le chef du village a ses conseillers, ses proches avec lesquelles es il discute et donne l'information à la population. Il convoque le conseil de famille et donne les informations. Généralement, il n'est pas tellement contesté. Il décide. Non, non le chef n'est pas contesté. BF-BD-RU-AKA-TA	The village chief has his advisors, his confidantes with whom he discusses and gives information to the population. He summons the family council and shares information. Generally, he will not be much challenged. He decides. No, no the chief will not be challenged. BF-BD-RU-AKA-TA
23	Chair of CVD of a rural village at local user level	Le village est organisé en fonction de groupements et de coopératives. De telle sorte qu'il y a essentiellement trois personnes ayant le pouvoir: il y a d'abord le CVD, la jeunesse – un ensemble de jeunes- dit quelque chose, l'imam [...] qui a un pouvoir incontestable dans le village. BF-VK-LU-UNA-PA	The village is organised based on groups and cooperatives. Essentially, there are three people with power: firstly, the CVD, then the Jeunesse - a group of young people - has a say and the Imam [...] also has an incontestable power in the village. BF-VK-LU-UNA-PA

Appendix

24	Religious leader from a rural village at local user level	When there is a piece of information to pass to the people, when the man gets the info, he goes to the leader: the chef de village, le conseiller et le cathecist. The chef de village and le conseiller will dispatch the piece of news to the village and in the meanwhile, the imam inform the people in the mosque and the cathecist inform the people to the churches. When there is a piece of information to transmit, that's easy. BF-BA-LU-DOU-SA	When there is a piece of information to pass to the people, when the man gets the info, he goes to the leader: the chef de village, le conseiller et le cathecist. The chef de village and le conseiller will dispatch the piece of news to the village and in the meanwhile, the imam informs the people in the mosque and the cathecist inform the people to the churches. When there is a piece of information to transmit, that's easy. BF-BA-LU-DOU-SA
25	Health professional in a regional CMA at regional technical level	Quand nous avons les agents de santé communautaires nous avons les correspondent dans le village; à coté de ce domaine-là tous les innovations dans le domaine de la santé impliquent les chefs coutumiers, religieux, chefs de villages, chefs de terre et ils font passer l'information car ils sont beaucoup plus écoutés. L'Imam, le chef coutumier, va transmettre. Nos correspondants dans les villages nous aident à passer l'information par rapport à l'innovation qu'on doit instaurer dans le domaine de la santé. BF-BD-RT-ERT-PO	We have the community health workers [and] we have the correspondents in the village. Besides this, all innovations in the health sector involve the 'leaders of tradition', religious leaders, village chiefs and land chiefs; they pass on the information because people listen to them. The Imam and the 'leader of tradition' will transmit [the messages]. Our correspondents in the villages help us to pass on the information concerning innovation that must be introduced in the health sector. BF-BD-RT-ERT-PO

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26	Executive manager within the Ministry of Health at national policy maker level	Sur le plan du paludisme, la population perçoit cela comme une maladie à la limite normale et c'est ce qui est déplorable. Tous les moyens de protection que nous mettons en œuvre ne sont pas toujours suivis. BF-OA-NP-ICE-CO	In terms of malaria, the population perceives this almost as a normal disease which is regrettable. All the protective measures that we are implementing are still not always being followed. BF-OA-NP-ICE-CO
27	Project Manager within the Ministry of Health at national technical level	Le palus est une maladie de tout le monde, tout le monde est avec le palus. C'est la maladie normale pour tout le monde. BF-OA-NT-ARD-AK	Malaria is seen as an everyday's disease, everybody has malaria. It's a normal disease for everyone. BF-OA-NT-ARD-AK
28	Religious leader from a rural village at local user level	Traditionally, when someone had malaria, they don't care very much, if it didn't pass they go to the traditional doctor. BF-BA-LU-DOU-SA	Traditionally, when someone had malaria, they don't care very much, if it didn't pass they go to the traditional doctor. BF-BA-LU-DOU-SA
29	Manager in a regional CMA at regional technical level	Le paludisme est une maladie assez fréquente et récurrente et facilement guérissable même sans traitement chez les personnes vivant avec le plasmodium, les germes du paludisme. [...] Il y a des erreurs d'appréciation qu'ils ne se rendent pas compte que cette maladie peut être aussi grave et mortel. BF-BD-RT-ARA-OU	Malaria is a frequent and recurring disease that is easily curable - even without treatment - for people carrying Plasmodium, the malaria germ. [...] There are assessment errors; people do not realise that the disease can also be serious and deadly. BF-BD-RT-ARA-OU
30	Member of an all-women focus group from a rural village at local user level	Quand on a le palu, la peau gonfle, on est tout fatigué, en regardant le visage on voit que c'est le palu. Focus Group 01	When one has malaria, the skin swells; one looks tired. Looking at the face one notices that it's malaria. Focus Group 01

Appendix

31	Executive director within the Ministry of Health at national policy maker level	Les populations la perçoivent comme une maladie courante. Lorsqu'il y a mortalité, ils ne font pas forcément le lien avec le paludisme, sauf peut-être avec des fétiches, des sorciers, c'est cela le comble. BF-OA-NP-NNE-VA	The populations perceive [malaria] as a common disease. With regards to mortality, the do not necessarily make the connection with malaria, except maybe with fetishes or sorcerers; that's the most. BF-OA-NP-NNE-VA
32	Socio-anthropologist at national user level	En général, dans nos cultures si quelqu'un est malade, on pense toujours que quelqu'un d'autre vous jeté un sort, c'est le cas dans la culture africaine. [...].Généralement on va chez le marabout ou le féticheur pour consulter au lieu d'aller tout suite au dispensaire ou à l'hôpital. [...] En particulier concernant des maladies qui frappent l'esprit, le paludisme, lorsque les enfants convulsent comme le tétanos, la méningite, cela survient brutalement et a des conséquences mortelles.	Generally in our cultures, if somebody is sick we always think that someone has cast a spell on your; that's the case in African culture. [...] Generally, we go to the marabou or the witch doctor for a consultation rather than going straightaway to the dispensary or the hospital. [...] Particularly concerning diseases that strike the mind, malaria, or when children are cramping, like with tetanus or meningitis, this occurs brutally and has mortal consequences.
33	Retired mayor of a mid-sized village at local user level	Dans le cas du paludisme. Quand un enfant à des convulsions, on dit que c'est dû à l'oiseau – c'est l'oiseau, c'est l'oiseau - et ça conditionne les gens sans qu'ils ne pensent au palus. On dit l'oiseau et c'est l'oiseau. BF-BD-LU-QUE-TR	In the case of malaria, if a child has cramps we say that this is due to the bird - 'it's the bird, it's the bird' - and this conditions people not to think of malaria. BF-BD-LU-QUE-TR

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34	Chief of a rural village at local user level	A chaque fois, il y a des associations qui l'expliquent. Ils disent que le moustique donne le paludisme, chaque fois. Jusqu'à présent des gens ne croient toujours pas à cela. Certains disent que c'est en mangeant des mangues, des repas gras. Les gens ne comprennent pas qui est le moustique qui transmet le paludisme mais ils ne comprennent pas. BF-VK-LU-IMA-OU	Every time, there are associations that explain it. They say that the mosquito transmits malaria, every time. Up until now, the people still don't believe that. Some say that it is caused by eating mangos or fatty meals. The people don't understand that it is the mosquito that transmits malaria - they don't understand. BF-VK-LU-IMA-OU
35	Member of an all-women focus group from a rural village at local user level	Le traitement qu'ils font à l'indigénat, ça peut durer habituellement un jour, si au bout d'un jour le traitement ne marche pas, ils peuvent aller dans le centre de santé. Focus Group 01	The traditional treatment they do usually lasts for one day. If at the end of that day the illness has not responded, they can go to the healthcare centre. Focus Group 01
36	Manager within the drug allocation department of the Ministry of Health at national managerial level	Tout dépend du premier motif de consultation et au Burkina c'est le paludisme. [...] Si vous lisez l'annuaire statistique, la première cause est le palus. BF-OA-NM-DJA-DJ	It all depends on the first reason for consultation and in Burkina Faso that is malaria. [...] If you read the annual statistics, the first reason is malaria. BF-OA-NM-DJA-DJ
37	Project Manager within the Ministry of Health at national technical level	Dans la plupart des documents sur la santé, le palus est la première cause de décès en Burkina. BF-OA-NT-ARD-AK	In most healthcare documents, malaria is listed as the leading cause of death in Burkina Faso. BF-OA-NT-ARD-AK
38	Regional director within the Ministry of Health at regional managerial level	Nous avons le même profil épidémiologique que les autres régions, avant tout le paludisme qui est un problème de santé publique. BF-BD-RM-ENT-ME	We have the same epidemiological profile as in other regions; above all malaria which is a public health concern. BF-BD-RM-ENT-ME

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39	Representative of a civil society group at regional user level	Actuellement il y a plein des maladies surtout le palus, la fièvre typhoïde et la sinusite actuellement aussi. BF-BD-RT-SSA-SA	Currently there are plenty of diseases, especially malaria, typhoid fever and currently also sinusitis BF-BD-RT-SSA-SA
40	Communication officer within the Ministry of Health at national policy maker level	Le facteur clef est la communication. La communication est primordiale pour que les nouvelles technologies soient bien appliquées par la population. Il faut miser sur la communication, l'information, la sensibilisation. BF-OA-NM-ICE-KI	The key factor is communication. Communication is essential so that new technologies are correctly used by the population. We need to focus on communication, information and awareness. BF-OA-NM-ICE-KI
41	Health professional in a regional CMA at regional technical level	Ils (la population) ont des habitudes qu'on leur demande de changer et ils ont de la peine à adopter de nouveaux comportements. Ça c'est le niveau de compréhension et le bien fondé du comportement qu'on dit de bloquer là; s'ils ne comprennent pas ça, ils vont être réticents. C'est le niveau de compréhension qui fait qu'il y a des réticences. BF-BD-RT-ERT-PO	They [the population] have habits that they are asked to change and they have difficulties adopting new behaviours. This is the level of understanding and the well-founded behaviour that is said to block it. If they don't understand this they will be reluctant. It's the level of understanding that leads to reluctance. BF-BD-RT-ERT-PO
42	Interim consultant for Ministry of Health at international managerial level	Il y a aussi le fait que dans les communautés, les hommes sont souvent réticents face à certaines interventions. BF-OA-IM-NNE-NA	There is also the fact that in the communities, men are often reluctant to respond to certain interventions. BF-OA-IM-NNE-NA

Appendix

43	Public Health professional within the PNLP at national policy maker level	Ces maladies durant quelques jours, ou bien un mois ou deux mois, quelques mois, le burkinabé les considère comme non naturelles ou parfois comme un sort. Ainsi, il dépense en moyens surnaturels avant de se rendre compte qu'il suffit de suivre les conseils de santé tout simplement pour que ça ne s'aggrave ou ne s'installe pas complètement. Ce problème fait partie des batailles liées à l'information d'arriver à faire changer d'avis par apport à ça. BF-OA-NP-LLE-DE	These diseases last for some days, or also a month or two months, some months, the Burkinabé consider them as unnatural or sometimes like a spell. Thus, [the people] invest in supernatural measures before realising that it would be enough to simply follow the health advice so that it doesn't get worse or settle in completely. This problem is part of the battle linked to the information in order to change the mind-set. BF-OA-NP-LLE-DE
44	Manager within the drug allocation department of the Ministry of Health at national managerial level	On essaie de les sensibiliser pour leur faire comprendre [...] L'habitude est une seconde nature. Il faut du temps pour laisser tomber les mauvaises habitudes sauf si tu as de la bonne volonté. Mais si ça paraît simple et que tu es convaincu de l'apport positif par rapport à ta pratique quotidienne, ça fonctionne. BF-OA-NM-DJA-DJ	We try to sensitise them in order to make them understand. [...] Habit is a second nature. It needs time to drop the bad habits unless you have good intentions. But if this seems easy and if you are convinced of the positive contribution to your daily practice, it works. BF-OA-NM-DJA-DJ

Appendix

45	Leading manager within a directorate of the Ministry of Environment at national user level	L'approche que utilise aujourd'hui: On fait de la sensibilisation, on fait des focus groupes, c'est une innovation. [...] Parce que aujourd'hui on ne peut pas éradiquer le mal mais il faut les sensibiliser, il faut les organiser de façon spatiale, donner des unités de traitement. [...] Il faut d'abord passer par la sensibilisation pour les amener à comprendre, comprendre quels sont les problèmes à venir et les solutions immédiates, qu'ils soient conscients du problème et poser la question de la solution. BF-OA-NU-IRE-YA	The approach that is used today: we create awareness, we conduct focus groups - that's an innovation. [...] Because today we cannot eradicate the evil but we need to sensitise them, to organise them spatially, to give them treatment units. [...] The first step is to raise awareness to enable them to understand: understand what the upcoming problems and the immediate solutions are so that they are aware of the problem and asking the question of the solution. BF-OA-NU-IRE-YA
46	Member of an all-women focus group from a rural village at local user level	She said that people refused to get their children vaccinated because, for example, if the child gets vaccinated, it may run fever and then, in that case, your work is disturbed all through the day. She also said that if your child get vaccinated it will die, and she has added that the new vaccines, particularly the one made on the side, is very painful and the day the child is vaccinated in that way, you are sure you won't be able to do anything else because he is so much elative, that you have to wait on him. Focus group 01	She said that people refused to get their children vaccinated because, for example, if the child gets vaccinated, it may run fever and then, in that case, your work is disturbed all through the day. She also said that if your child get vaccinated it will die, and she has added that the new vaccines, particularly the one made on the side, is very painful and the day the child is vaccinated in that way, you are sure you won't be able to do anything else because he is so much elative, that you have to wait on him. Focus group 01

Appendix

47	Member of an all-women focus group from a rural village at local user level	She said “how can’t you get aware when you have your child ill and you refuse to get him vaccinated? Your neighbour gets his vaccinated, his got saved and yours is dying. In that case you know the advantage of vaccination”. Focus Group 01	She said “how can’t you get aware when you have your child ill and you refuse to get him vaccinated? Your neighbour gets his vaccinated, his got saved and yours is dying. In that case you know the advantage of vaccination”. Focus Group 01
48	Chief of a rural village at local user level	Au début c’était difficile, des femmes ne voulaient pas faire vacciner leurs enfants. Mais un jour la rougeole a attaqué le quartier est nous avons su qui ne c’était pas vacciné et a pris la rougeole...mais par la suite, tout le monde s’est vacciné. Maintenant tous les enfants sont vaccinés. BF-VK-LU-IMA-OU	In the beginning it was difficult; the women did not to vaccinate their children. But one day, the measles attacked the neighbourhood and we knew that everyone who was not vaccinated got the measles ... afterwards, everyone got vaccinated. Now, all children are vaccinated. BF-VK-LU-IMA-OU
49	Member of an international NGO at international user level	Quand c’est nouveau, les gens ne comprennent pas. Ils ont besoin de comprendre, et généralement l’activité nouvelle que vous apporté mérite de longues préparations pour sensibiliser la communauté ou vous allez vous retrouver seul et vous êtes en train d’amener d’activité qui ne marchent pas. Pour tous qui sont nouveau il faut prendre le temps pour expliquer, il faut démarrer tôt les préparatifs si on veut avoir un impact avec le projet. Il faut que vous en soyez sûr dans l’immédiat et le long terme. BF-OA-IU-AKA-SO	When it's new people don't understand. They need to understand and generally any new activity that you introduce requires long preparations in order to sensitise the community; otherwise, you will find yourself lone and are bringing in an activity that does not work. For everything that is new you need to take the time to explain; it is necessary to start preparations early if you want to have an impact with the project. You need to be sure of this in the short- and mid-term. BF-OA-IU-AKA-SO

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50	Member of an all-women focus group from a rural village at local user level	Doctors would tell them that what they want, what they do, vaccination is not something bad. They tell them the advantage. Some accept, some others refuse. In that case, if you have refused, and the disease comes and you see that your child gets more attacked than other children, then you come to understand. Focus group 01	Doctors would tell them that what they want, what they do, vaccination, is not something bad. They tell them the advantage. Some accept, some others refuse. In that case, if you have refused, and the disease comes and you see that your child gets more attacked than other children, then you come to understand. Focus group 01
51	Representative of a civil society group at regional user level	Quand une population se rebelle contre son préfet, il y a problème, la population n'a pas confiance en son préfet. Dans le cas contraire, ils auraient communiqué. Donc la distance sociale était grande. BF-BD-RU-ANA-BE	When a population rebels against its prefect, there is a problem: the population does not trust its prefect. Otherwise, they would have communicated. Thus, the social distance was large. BF-BD-RU-ANA-BE
52	Retired health professional at regional user level	Les gens doivent voir les avantages de l'innovation. C'est-à-dire c'est une référence. Quand il y a des innovations il y a des avantages. BF-BD-RU-AKA-TA	The people need to see the advantages of innovation, meaning that it is a reference. When there are innovations there are advantages. BF-BD-RU-AKA-TA
53	Member of an all-women focus group from a rural village at local user level	Elle dit que celles qui refusent, c'est parce que elles n'ont pas compris. Et que maintenant elle est revenue sur les avantages, les gens maintenant ont compris et vont jusqu'à Nasso pour se faire guérir. Focus group 01	She said that those who refuse it do it because they have not understood. And now that she has come back to the advantages, people have understood and travel until Nasso in order to get treatment. Focus group 01

Appendix

54	Manager in a regional CMA at regional technical level	S'ils ont une mauvaise expérience par rapport à un cas, [...] de bouche à oreille on te dira que ça tue et ça c'est un élément qui peut constituer un frein à l'acceptabilité de ces innovations. BF-BD-RT-ARA-OU	If they have had a bad experience in one case, they will tell you by word to mouth that [the innovation] will kill. This is an element that can constitute a hurdle towards acceptance of those innovations. BF-BD-RT-ARA-OU
55	Manager within the drug allocation department of the Ministry of Health at national managerial level	L'habitude est une seconde nature. Il faut du temps pour laisser tomber les mauvaises habitudes sauf si tu as de la bonne volonté. Mais si ça paraît simple et que tu es convaincu de l'apport positif par rapport à ta pratique quotidienne, ça fonctionne. Mais quand est compliqué... BF-OA-NM-DJA-DJ	Habit is a second nature. It needs time to drop the bad habits unless you have good intentions. But if this seems easy and if you are convinced of the positive contribution to your daily practice, it works. But if it is complicated... BF-OA-NM-DJA-DJ
56	Communication officer of a national NGO at national managerial level	Ce sont des facteurs de résistance. Si l'innovation est compliquée, la réalisabilité est difficile à obtenir. Il faut simplifier les protocoles d'utilisation face à des gens souvent analphabètes. BF-OA-NM-RRE-OU	Those are factors of resistance. If the innovation is complicated it is difficult to realise it. It is necessary to simplify usage protocols when dealing with people who are often illiterate. BF-OA-NM-RRE-OU
57	Founder and leader of national NGO at national managerial level	Je me rappelle le Directeur de publication de l'Observateur avait posé ce problème à une conférence, il avait essayé d'ouvrir une page pour des articles en Mòoré, mais comme les gens ont la logique académique, ils ont voulu faire de l'académie morophone et sont allés chercher des mots trop compliqués à tel point qu'on ne comprend plus rien. BF-OA-NM-MON-KA	I remember the editor of the Observer had brought up this topic at a conference: had tried to open a page for articles in Mòoré. But since the people have an academic logic, they wanted to build a morophone academy and tried to use too complicated words. At that point nobody understood anything any longer. BF-OA-NM-MON-KA

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58	Member of an international NGO at international user level	Il faut parler d'une façon accessible à la population. On ne le faisait pas il y a 10 ans mais nous informons les gens à présent. BF-OA-IU-AKA-SO	It crucial to speak in a way that is accessible to the population. We did not do this 10 years ago but we are informing the people now. BF-OA-IU-AKA-SO
59	Member of an international NGO at international user level	L'information n'est pas facile à digérer, le mot pour les gens veut dire la mort. Ce sont des démarches nouvelles pour prendre du recul et trouver les mots justes et réduire à un langage compréhensible. BF-OA-IU-AKA-SO	Information is not easy to digest; the word means death for the people. Those are new approaches to step back and find appropriate words and reduce them to an understandable language. BF-OA-IU-AKA-SO
60	Technical consultant of an international NGO at international managerial level	Si on communique mieux avec la population, ils comprendront. [...] La communication reste la porte d'entrée, il faut avoir le consensus, c'est la clé de la réussite. BF-OA-IM-UEL-KA	If we communicate better with the population they will understand. [...] Communication remains the gateway; it is important to have consensus which is key to success. BF-OA-IM-UEL-KA
61	Doctor at a regional hospital at regional technical level	Quand on va renforcer la confiance c'est toujours bon. La création de la confiance est très importante, surtout si on ne politise pas les choses, on évite dans le domaine de la santé car ça divise la population. BF-BD-RT-DOU-GA	When we strengthen trust, it is always good. Building trust is very important, especially if we don't politicise things. We avoid this in the healthcare sector because it divides the population. BF-BD-RT-DOU-GA

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62	Member of an international NGO at international user level	Quand c'est nouveau, les gens ne comprennent pas. Ils ont besoin de comprendre, et généralement l'activité nouvelle que vous apporté mérite de longues préparations pour sensibiliser la communauté ou vous allez vous retrouver seul et vous êtes en train d'amener d'activité qui ne marchent pas. BF-OA-IU-AKA-SO	When it's new people don't understand. They need to understand and generally any new activity that you introduce requires long preparations in order to sensitise the community; otherwise, you will find yourself lone and are bringing in an activity that does not work. BF-OA-IU-AKA-SO
63	Communication officer within the Ministry of Health at national policy maker level	Maintenant, au niveau local, il y a une phase, un période, d'information afin d'informer la population du passage à une date précise, avant que la campagne ne débute. BF-OA-NM-ICE-KI	Now, at the local level, there is a phase/a period of information in order to inform the population of the shift towards a specific date, before the campaign begins. BF-OA-NM-ICE-KI
64	General Secretary of a governmental administration at regional user level	On a le feedback puisqu'on fait des communiqués sur les zones par la radio, les télévisions, et passe en large diffusion et toute la population est informé. BF-BD-RU-SSA-SA	We have feedback because we release press communication on the areas via radio, TV and broadcasts and the whole population is informed. BF-BD-RU-SSA-SA
65	General Secretary of a governmental administration at regional user level	Nous devons mieux communiquer afin qu'ils puissent comprendre. [...] Dans les villes il y a la radio, la télévision, internet mais dans les villages, c'est vrai qu'il y a la radio mais il y a aussi les crieurs publics avec son tam-tam. C'est la meilleure méthode de communication. Dès qu'il tape tout le monde écoute, ce n'est pas n'importe qui. Dans les villages quand le crieur public commence à taper, tout le monde l'écoute. BF-BD-RU-SSA-SA	We need to communicate better so that they can understand. [...] In the cities they have radio, television and internet; in the villages it is true that they have radio but there is also the public crier with their tam-tam. This is the better way of communication. As soon as he taps everyone is listening, no matter who. Once the public crier begins to tap in the villages everyone listens in. BF-BD-RU-SSA-SA

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66	General Secretary of a governmental administration at regional user level	D'abord, il y a en amont le mode de communication comme les publicités de sensibilisation faites du Ministère de la Santé. BF-BD-RU-SSA-SA	Firstly, there has been an improvement in the way off communication, for example the sensibilisation campaign by the Ministry of Health. BF-BD-RU-SSA-SA
67	Doctor at a regional hospital at regional technical level	Au niveau des formations sanitaires, on a des mobilisateurs, des crieurs publics et des agents de santé à base communautaire. Pour introduire une nouvelle innovation dans le district, on utilise les trois stratégies de communication pour le développement: le plaidoyer, la mobilisation sociale et la communication pour le changement. BF-BD-RT-DOU-GA	At the level of health facilities, there are mobilizers, public criers and community-based health workers. To introduce a new innovation in the district, the three communication strategies for development are used: advocacy, social mobilisation and communication for change. BF-BD-RT-DOU-GA
68	Project Manager of a regional NGO at regional managerial level	Sur le terrain, les approches diffèrent selon les contextes. En milieu rural, les agents de santé à base communautaire que nous impliquons et qui sont chargés de la mobilisation sociale, de convaincre les gens pour qu'ils assistent aux causeries. C'est ce que font nos associations sur le terrain. S'il y a des difficultés, les ASC passent par le chef du village ou le chef religieux pour que les activités se mènent. Cette approche est la même au niveau de notre clinique qui lorsqu'elle passe sur le terrain procède ainsi. Ils font la mobilisation avant et le jour de l'activité. BF-BD-RM-UES-SA	On the ground, the approaches differ depending on the context. In rural areas, the community-based health workers, that we employ and who are in charge of social mobilisation, are tasked to convince the people to attend the talks. This is what our associations do in the field. If there are difficulties, the CHWs go through the village chief or religious leader for the activities to take place. This approach is the same at the level of our clinic which takes the same route on the ground. They do the mobilisation before and on the day of the activity. BF-BD-RM-UES-SA

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69	District mayor of a city at regional user level	Souvent, [sans l'acceptation du chef] le projet est perdu. Nous expliquons au chef que nous ne sommes pas les décideurs mais le lieu en lui-même, les sols décide où il y a d'eau. Ainsi, s'il refuse l'accès, ils n'auront pas l'eau potable. BF-BD-RU-OUF-OU	Often, [without the acceptance by the chief] the project is lost. We explain to the chief that we are not the decision makers but the community in itself; the soil decides where there is water. Thus, if he refuses access, they will not have drinking water. BF-BD-RU-OUF-OU
70	Retired mayor of a mid-sized village at local user level	Nous impliquons les responsables locaux, les chefs du village, les adjoints, les envoyés, le cvd du village, les chefs coutumiers. Alors, les gens viennent car eux participent. On a besoin de leur aide technique. Les gens dit: il y a le coutumiers..... les gens viennent. Si on a les moyens ça passe. BF-BD-LU-QUE-TR	We involve the local leaders: village chiefs, deputies, envoys, the CVD of the village, as well as the 'leader of tradition'. So people come because they participate. We need their technical help. The people say: 'there are the traditional leaders'... and then they come. If we have the means this works. BF-BD-LU-QUE-TR
71	Regional director within the Ministry of Health at regional managerial level	Les chefs coutumiers et aussi les leaders religieuses maintenant l y a aussi les leaders politiques à présent et associatifs qu'on utilise beaucoup [pour la divulgation d'informations], ce sont des éléments non négligeables. BF-BD-RM-ENT-ME	We use the 'leaders of tradition' and the religious leaders, nowadays also political leaders and associates, a lot [for the diffusion of information]; those are not insignificant elements. BF-BD-RM-ENT-ME
72	Chair of CVD of a rural village at local user level	Si je prends une décision moi avec le chef du village, toute la population suit. On s'organise en faisant un groupe avec l'imam, avec les vieux. On voit ce que doit faire, on prend une décision pour voir ce que doit être fait dans ce quartier. BF-VK-LU-UNA-PA	If I take a decision with the chief of the village, the entire populations follows. We organise ourselves by forming a group with the Imam and the Elders. We see what needs to be done and we take a decision to initiate what needs to be done in the neighbourhood. BF-VK-LU-UNA-PA

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73	Regional director within the Ministry of Health at regional managerial level	L'efficacité et la réaction au produit doit être prouvée mais on ne le fait pas. On ne parle qu'au grand public mais on doit isoler les gens contre et les convaincre et là les leaders peuvent nous aider. BF-BD-RM-ENT-ME	Efficacy of and reaction to the product must be proven but we don't do this. We only speak to the larger public but we need to isolate the people and convince them - and there the leaders can help us. BF-BD-RM-ENT-ME
74	Regional director within the Ministry of Health at regional managerial level	L'acceptabilité culturelle compte tout comme la perception qu'il faut vaincre. BF-BD-RM-ENT-ME	Cultural acceptability counts as much as the perception that needs to be overcome. BF-BD-RM-ENT-ME
75	Communication officer of a national NGO at national managerial level	Il n'y a pas de critère universel [pour l'acceptation], ça dépend du milieu, de l'innovation, de beaucoup de facteurs pouvant influencer et varier d'un milieu à l'autre. Les choses appréciées ne sont pas toujours les mêmes. Ça dépend de l'échelle des valeurs des communautés. Il y a des différentes valeurs entre les communautés. BF-OA-NM-RRE-OU	There is no universal criterion [for acceptance]. It all depends on the communities, on innovation and on many factors that can influence and vary from one community to another. The things that are appreciated are not always the same. This depends on the range of values of the communities; there are different values between the communities. BF-OA-NM-RRE-OU
76	Technical consultant of an international NGO at international managerial level	Nous avons beaucoup travaillé avec le monde communautaire: associations et groupements, de sorte que nous les avons formées sur la planification familiale, équipé avec des informations, des messages pour la communauté. BF-OA-IM-UEL-KA	We have worked intensively within the community world, with associations and groups. We have trained them on family planning, equipped them with information and with messages for their communities. BF-OA-IM-UEL-KA

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77	Founder and leader of national NGO at national managerial level	Un travail transversal sur l'apport communautaire, car pour nous il faut réformer et innover mais ça doit venir de la base. Jusqu'à présent, on a senti des réformes qui viennent d'en haut, top-down, mais ils mettent en place des réformes décalées avec les réalités, c'est-à-dire qu'on fait la planification, les innovations sur la base des préoccupations que les décideurs ont, pas sur la base de celles des populations. BF-OA-NM-MON-KA	[This is] a transversal work on community input. For us it is important to reform and innovate but this needs to come from the base. Until now, we have seen reforms that are coming from the top - top-down. But they implement reforms that are remove from reality. This means that we do the planning and the innovations based on the concerns of the decision makers and not based on those of the population. BF-OA-NM-MON-KA
78	Representative of a civil society group at regional user level	Des gens dans la communauté auront toujours peur et d'autres accepteront d'adhérer. Les premiers donneront le courage aux autres, malgré les risques. BF-BD-RU-ANA-BE	Some people in the community will always be afraid and others will agree to join. The former will encourage the others, despite the risks. BF-BD-RU-ANA-BE
79	General Secretary of a network of NGOs at national technical level	D'abord on se méfie de la nouveauté, c'est culturel. On ne sait pas quels bouleversements ça va créer. Comme tu n'es pas sûr de maîtriser, tu te méfies et observes. [...] Pour amener quelque chose de nouveau, il faut étudier le milieu car la méfiance est d'abord culturelle, jusqu'à ce que les innovateurs nous prouvent. Il faut prendre en compte les aspects culturels, la perception du produit et l'accessibilité et aussi l'adhésion des gens. 39 Interview A B C D	At first, we are suspicious of any change, that's cultural. We do not know which kind of changes this will create. As you are not sure if you can manage this, you remain suspicious and observe. [...] In order to bring in something new we need to study the environment because the suspicion is mainly cultural; [it remains] until the innovators prove it to us. We need to take into account the cultural aspects, the perception of the product, accessibility and also the support of the population. 39 Interview A B C D

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80	Retired health professional at regional user level	Ça dépendra de l'innovation, si elle s'approche du culturel ou non. S'il n'y a pas des problèmes culturels peuvent passer sans problèmes. [...] L'innovation, si elle se mêle au culturel, a besoin que l'on casse ce lien. BF-BD-RU-AKA-TA	It depends on the innovation whether it embraces the cultural aspect or not. If there are no cultural problems it can pass without problems. [...] If innovation mixes with the cultural [dimension] it is necessary to cut that link. BF-BD-RU-AKA-TA
81	Executive manager within the Ministry of Health at national policy maker level	Toutes ces conceptions socio-économiques et culturelles erronées font qu'on a toujours ces problèmes de santé à tous niveaux. Il faut beaucoup de communication pour amener les gens à accepter, à comprendre et c'est à ce prix-là que nous pourrions obtenir des résultats et réduire les maladies. BF-OA-NP-ICE-CO	All these erroneous socio-economic and cultural conceptions mean that we still have these health problems at all levels. It takes a lot of communication to get people to accept, to understand, and that's where we can get results and reduce disease. BF-OA-NP-ICE-CO
82	Representative of a civil society group at regional user level	Si c'est bon ils vont communiquer entre eux. Par le bouche à oreille, les gens viennent. BF-BD-RT-SSA-SA	If it is good they will communicate with each other. By word of mouth, people will come. BF-BD-RT-SSA-SA
83	General Secretary of a network of NGOs at national technical level	Si tu dis quelque chose, la rumeur part et le contraire du message tourne. Comme pour le refus des génériques, si le médecin ne prescrit pas, alors le mot va passer et se transformer du bouche à oreille. Personne ne vérifiera. 39 Interview A B C D	If you say something, the rumours are starting and the opposite message returns. Like for the refusal of generics: if the doctor does not prescribe it, then the word will pass and will be transformed by word to mouth. Nobody will verify. 39 Interview A B C D

Appendix

84	Manager in a regional CMA at regional technical level	Quand on utilise de bons canaux pour les convaincre nous ne rencontrons pas de problèmes. BF-BD-RT-ARA-OU	When we use good channels to convince them we do not encounter problems. BF-BD-RT-ARA-OU
85	Qualified nurse at a local hospital at local technical level	Il y a aussi les rumeurs pouvant partir d'un individu dans la population, se disant connaisseur, que ce soit un semi-lettré, proche d'un agent de santé ou sachant un peu lire, et qui déformera une information ou la scandalisera. Cela peut être à l'origine souvent du refus d'une innovation. BF-BD-LT-ICE-KY	There are also rumours that are started by an individual within the population, a self-proclaimed expert, who could be semi-literate, close to a health worker or knowing how to read a little and who could distort or scandalise information. This can often be the source of the refusal of an innovation. BF-BD-LT-ICE-KY
86	Regulatory affairs specialist	[...] opposition groups. They have a lot of money to spend, and a lot of effort that they can use to oppose and that's been a problem all along especially in countries in Africa where you have well-funded opposition groups going up against these regulatory agencies.	[...] opposition groups. They have a lot of money to spend, and a lot of effort that they can use to oppose and that's been a problem all along especially in countries in Africa where you have well-funded opposition groups going up against these regulatory agencies.
87	Regulatory affairs specialist	Anybody who is ideologically opposed to a genetic modification may support local people on the ground - and have done frequently.	Anybody who is ideologically opposed to a genetic modification may support local people on the ground - and have done frequently.
88	Regulatory affairs specialist	In Burkina you've got a ministerial sign off so you have to have that political will, they want to see this project go ahead, they want to do this politically, otherwise it will influence regulatory, if they have a negative public comment period	In Burkina you've got a ministerial sign off so you have to have that political will, they want to see this project go ahead, they want to do this politically, otherwise it will influence regulatory, if they have a negative public comment period

Appendix

89	Regulatory affairs specialist	I think it [political engagement or commitment] would be very applicable here. I think it will work in a positive way also for us also because of the burden of malaria.	I think it [political engagement or commitment] would be very applicable here. I think it will work in a positive way also for us also because of the burden of malaria.
90	Regulatory affairs specialist	I think this is driven totally by what your regulatory trigger is. So in order to produce a dossier, you have to know under which law you are applying, and what the procedure is. So, some countries have the genetic modification as such. [...] You have to apply because it's genetically modified, so that's a process-based trigger. Other countries have a product-based trigger, so this product does vector control and there may be other legislations that are triggered because of that	I think this is driven totally by what your regulatory trigger is. So in order to produce a dossier, you have to know under which law you are applying, and what the procedure is. So, some countries have the genetic modification as such. [...] You have to apply because it's genetically modified, so that's a process-based trigger. Other countries have a product-based trigger, so this product does vector control and there may be other legislations that are triggered because of that
91	Regulatory affairs specialist	Nevertheless, even if you have a sound legislation [...] you may...] have no resources to implement it	Nevertheless, even if you have a sound legislation [...] you may...] have no resources to implement it
92	Regulatory affairs specialist	What helps regulators is knowledge. So if you got knowledge, whether it's from published papers or from doing the same thing in other countries, whether it is from other people doing the same thing, which helps them come to an easier decision.	What helps regulators is knowledge. So if you got knowledge, whether it's from published papers or from doing the same thing in other countries, whether it is from other people doing the same thing, which helps them come to an easier decision.

Appendix

93	Regulatory affairs specialist	Just the uncertainty of governments. Right now Burkina Faso is in a good place as far as their regulatory structure not being too affected by what has happened over the last few years politically. It seems like Burkina Faso has managed to keep going despite some political upheaval, but if things should change drastically, I think that could cause a problem	Just the uncertainty of governments. Right now Burkina Faso is in a good place as far as their regulatory structure not being too affected by what has happened over the last few years politically. It seems like Burkina Faso has managed to keep going despite some political upheaval, but if things should change drastically, I think that could cause a problem
94	Regulatory affairs specialist	The ability of the NBA to conduct the assessment of the application and the evaluation of the application, in a way that gives them the confidence that they've done their job properly. And that includes the confidence that they conducted a proper risk assessment to take the decision.	The ability of the NBA to conduct the assessment of the application and the evaluation of the application, in a way that gives them the confidence that they've done their job properly. And that includes the confidence that they conducted a proper risk assessment to take the decision.
95	Regulatory affairs specialist	Regulators should be allowed to make decisions based on analyses and risk assessments they do themselves and make sense to them, because those are the ones they will be best able to defend	Regulators should be allowed to make decisions based on analyses and risk assessments they do themselves and make sense to them, because those are the ones they will be best able to defend
96	Regulatory affairs specialist	This should include someone who makes sure that the decision making process and the transmission of the documents and consideration of the documents is done in a timely way and doesn't let things lag behind	This should include someone who makes sure that the decision making process and the transmission of the documents and consideration of the documents is done in a timely way and doesn't let things lag behind

Appendix

97	Regulatory affairs specialist	Safety should be intrinsic to the product, providing evidence that this thing is going to work and that it is worth the enthusiasm that they will have for this technology and the effort they will have to support the deployment of this technology by rendering positive decisions	Safety should be intrinsic to the product, providing evidence that this thing is going to work and that it is worth the enthusiasm that they will have for this technology and the effort they will have to support the deployment of this technology by rendering positive decisions
98	Regulatory affairs specialist	One thing I wouldn't necessarily call hurdle or barrier, but it's something that a project necessarily has to be successful at – is the demonstration of efficacy. Providing evidence that this thing is going to work and that it is worth the enthusiasm that they [regulators] will have for this technology and the effort they will have to support the deployment of this technology by rendering positive decisions. So I think that's something that you really need.	One thing I wouldn't necessarily call hurdle or barrier, but it's something that a project necessarily has to be successful at – is the demonstration of efficacy. Providing evidence that this thing is going to work and that it is worth the enthusiasm that they [regulators] will have for this technology and the effort they will have to support the deployment of this technology by rendering positive decisions. So I think that's something that you really need.

Appendix

99	Regulatory affairs specialist	Trust and credibility. So if you put in an application which you have to change and say “well, sorry we got that wrong” it doesn’t look like you’re very trustworthy, like you’ve not got much credibility, because to a regulator it seems you might not know what you’re doing.[...] It’s about building up a dialogue, trust, a rapport with the regulator, as well. So they understand you, they trust you, you know, they trust the messenger.	Trust and credibility. So if you put in an application which you have to change and say “well, sorry we got that wrong” it doesn’t look like you’re very trustworthy, like you’ve not got much credibility, because to a regulator it seems you might not know what you’re doing.[...] It’s about building up a dialogue, trust, a rapport with the regulator, as well. So they understand you, they trust you, you know, they trust the messenger.
100	Regulatory affairs specialist	Regulators have the obligation to consider whatever application they are submitted to them, but certainly it makes them much more engaged and enthusiastic, if it is an application for a technology that they know is going to do something really beneficial.	Regulators have the obligation to consider whatever application they are submitted to them, but certainly it makes them much more engaged and enthusiastic, if it is an application for a technology that they know is going to do something really beneficial.

Appendix

101	Regulatory affairs specialist	Regulators tend to look at what's in front of them at the time. They don't tend to think this is a program. Developers might think it's a program, but they tend to look at the dossier in front of them at the time. So I think one of the barriers that might be encountered is the release of genetically modified insects is seen as quite controversial. If that doesn't provide any benefits to those people, i.e. we're not getting rid of malaria through precursor stages of the technology, then why releasing....so if they don't perceive a benefit to them it becomes tricky	Regulators tend to look at what's in front of them at the time. They don't tend to think this is a program. Developers might think it's a program, but they tend to look at the dossier in front of them at the time. So I think one of the barriers that might be encountered is the release of genetically modified insects is seen as quite controversial. If that doesn't provide any benefits to those people, i.e. we're not getting rid of malaria through precursor stages of the technology, then why releasing....so if they don't perceive a benefit to them it becomes tricky
102	Regulatory affairs specialist	It happened in Malaysia. They wanted to do it in a very controlled way, but after the first trial it stopped, because nobody could see any benefit. Not because there wasn't one, just because the trial wasn't designed to produce these benefits	It happened in Malaysia. They wanted to do it in a very controlled way, but after the first trial it stopped, because nobody could see any benefit. Not because there wasn't one, just because the trial wasn't designed to produce these benefits
103	Regulatory affairs specialist	The perception of what this technology is going to bring to you is crucial.	The perception of what this technology is going to bring to you is crucial.

Appendix

104	Regulatory affairs specialist	There might be a boredom with those [engagement] conversations after a while, what calls site fatigue, especially if things get further and further delayed, so, you know, in here if we spend ten years in a regulatory process trying to get it approved, then they'll say "yeah but you said it would come ten years ago, why isn't it here, what're you doing, you do not know what you are doing..." you know, that sort of thing particularly if you're still trapped in the villages or still trying to get data out to those villages, then there's a sort of fatigue element that sets in and they say "oh go away you're never going to bring me this stuff. I don't want you here in my village anymore." You know that could be a possibility	There might be a boredom with those [engagement] conversations after a while, what calls site fatigue, especially if things get further and further delayed, so, you know, in here if we spend ten years in a regulatory process trying to get it approved, then they'll say "yeah but you said it would come ten years ago, why isn't it here, what're you doing, you do not know what you are doing..." you know, that sort of thing particularly if you're still trapped in the villages or still trying to get data out to those villages, then there's a sort of fatigue element that sets in and they say "oh go away you're never going to bring me this stuff. I don't want you here in my village anymore." You know that could be a possibility
105	Regulatory affairs specialist	The further we get along in the process, the higher the complexity, the more they may seek additional reviews, or when we get to a gene drive product, for example, they may say 'well let's have a socio-economic review	The further we get along in the process, the higher the complexity, the more they may seek additional reviews, or when we get to a gene drive product, for example, they may say 'well let's have a socio-economic review

Appendix

106	Regulatory affairs specialist	But I think what's different from gene-drives is normally [...] I mean this is what we're doing here, we're building up credibility and information with the committee, but they are 3 separate products, normally you'd have the same product that you take through each of the steps, but we're just doing step-wise in a different way. So the product that you want release at the end, the gene-drive product isn't the same as the product that you are seeing now, which is male sterile. And so what we're trying to do is to make sure they recognize elements from the male sterile that are equally applicable to gene-drive, such as the marker gene, for example.	But I think what's different from gene-drives is normally [...] I mean this is what we're doing here, we're building up credibility and information with the committee, but they are 3 separate products, normally you'd have the same product that you take through each of the steps, but we're just doing step-wise in a different way. So the product that you want release at the end, the gene-drive product isn't the same as the product that you are seeing now, which is male sterile. And so what we're trying to do is to make sure they recognize elements from the male sterile that are equally applicable to gene-drive, such as the marker gene, for example.
107	Regulatory affairs specialist	And I think the final factor that I would say is just good public engagement [...]. I think it is so key to the acceptance and adoption of a technology. As in fact, the population acceptance plays a major role.	And I think the final factor that I would say is just good public engagement [...]. I think it is so key to the acceptance and adoption of a technology. As in fact, the population acceptance plays a major role.
108	Regulatory affairs specialist	[Population acceptance] and its impact down the regulatory system: I think it makes the job of the regulators a lot easier if they aren't faced with making a decision that is going to be so unpopular to the public that they are going to have a difficult time making that decision.	[Population acceptance] and its impact down the regulatory system: I think it makes the job of the regulators a lot easier if they aren't faced with making a decision that is going to be so unpopular to the public that they are going to have a difficult time making that decision.

Appendix

109	Regulatory affairs specialist	The thing that comes most to mind is once again the importance of public acceptance. Everything falls apart if there is no public acceptance.	The thing that comes most to mind is once again the importance of public acceptance. Everything falls apart if there is no public acceptance.
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12.7 Regional Directions and Healthcare Districts in Burkina Faso

Direction Régionale de la Santé de la Boucle du Mouhoun:	Direction Régionale de la Santé de l'Est:	Direction Régionale de la Santé des Cascades:
District Sanitaire de Boromo	District Sanitaire de Gayeri	District Sanitaire de Banfora
District Sanitaire de Dédougou	District Sanitaire de Bogandé	District Sanitaire de Mangodara
District Sanitaire de Nouna	District Sanitaire de Diapaga	District Sanitaire de Sindou
District Sanitaire de Solenzo	District Sanitaire de Fada	
District Sanitaire de Toma	District Sanitaire de Manni	
District Sanitaire de Tougan	District Sanitaire de Pama	

Direction Régionale de la Santé des Hauts-Bassins:	Direction Régionale de la Santé du Centre:	Direction Régionale de la Santé du Centre-Est:
District Sanitaire de Dafra	District Sanitaire de Baskuy	District Sanitaire de Koupéla
District Sanitaire de Dandé	District Sanitaire de Bogodogo	District Sanitaire de Bittou
District Sanitaire de Dô	District Sanitaire de Boulmiougou	District Sanitaire de Garango
District Sanitaire de Houndé	District Sanitaire de Nongr-Massom	District Sanitaire de Ouargaye
District Sanitaire de Karangasso Vigué	District Sanitaire de Sig-Noghin	District Sanitaire de Pouytenga
District Sanitaire de Léna		District Sanitaire de Tenkodogo
District Sanitaire de Orodara		District Sanitaire de Zabré

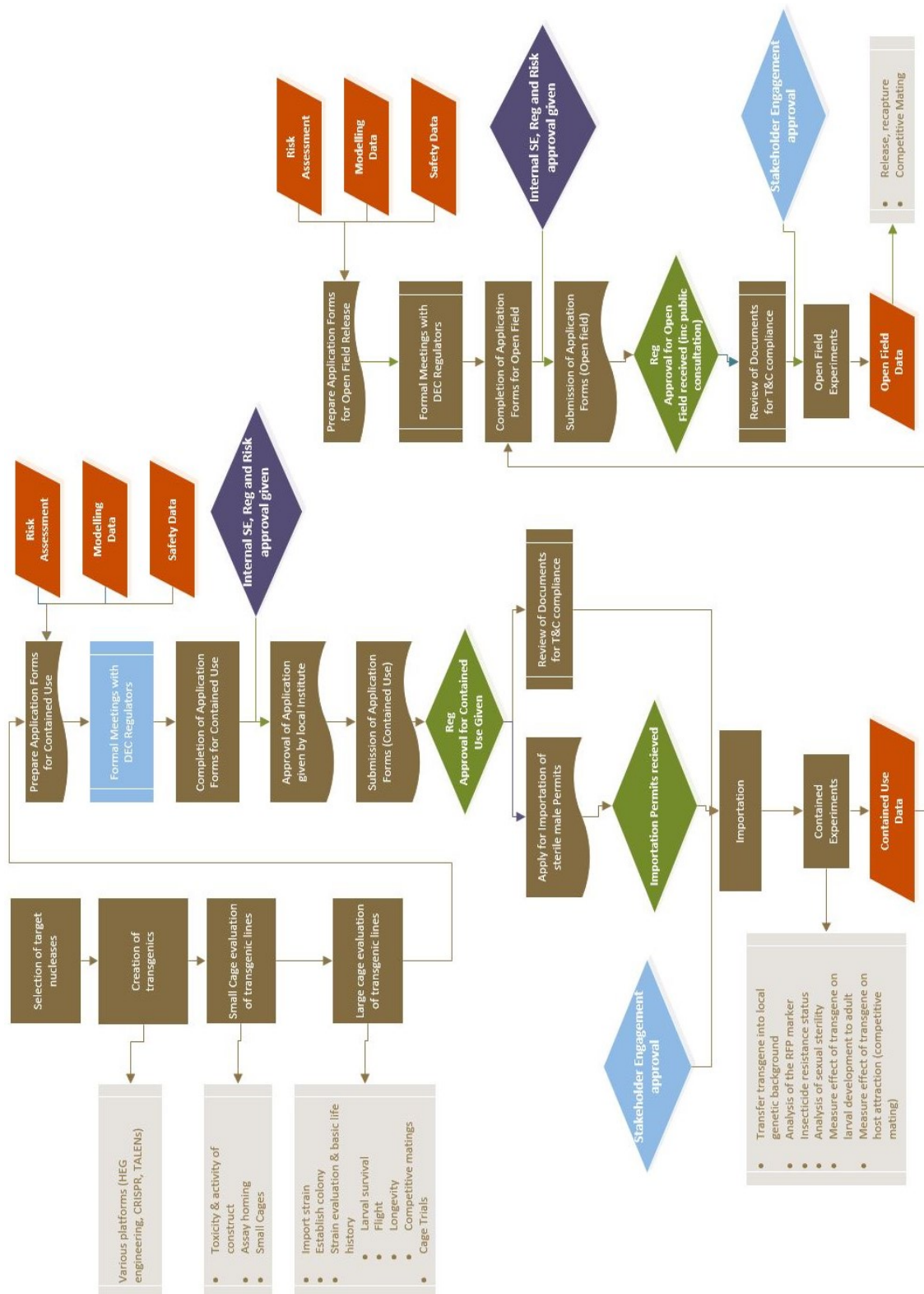
Appendix

Direction Régionale de la Santé du Centre-Nord:	Direction Régionale de la Santé du Centre-Ouest:	Direction Régionale de la Santé du Centre-Sud:
District sanitaire de Barsalogho District sanitaire de Boulsa District Sanitaire de Kaya District sanitaire de Kongoussi	District Sanitaire de Koudougou District Sanitaire de Léo District Sanitaire de Nanoro District Sanitaire de Réo District Sanitaire de Sapouy	District Sanitaire de Kombissiri District Sanitaire de Manga District Sanitaire de Pô District Sanitaire de Saponé

Direction Régionale de la Santé du Nord:	Direction Régionale de la Santé du Plateau Central:	Direction Régionale de la Santé du Sahel:
District Sanitaire de Gourcy District Sanitaire de Ouahigouya District Sanitaire de Séguenega District Sanitaire de Titao District Sanitaire de Yako	District Sanitaire de Boussé District Sanitaire de Ziniaré District Sanitaire de Zorgho	District Sanitaire de Djibo District Sanitaire de Dori District Sanitaire de Gorom-Gorom District Sanitaire de Sebba

Direction Régionale de la Santé du Sud-Ouest:
District Sanitaire de Batié District Sanitaire de Dano District Sanitaire de Diébougou District Sanitaire de Gaoua

12.8 Detailed view of Target Malaria's technology development pipeline



12.9 Descriptive statistics for the independent variables of the econometric model (Chapter 8)

Household (HR) recode

	p25	p50	p75	sd	min	max
Region	4	7	10	3.705754	1	13
Type of place of residence	0	0	1	.4409884	0	1
Religion	1	2	3	1.075517	0	4
Ethnicity	6	7	7	21.20763	1	98
Sex of head of household	1	1	1	.3068318	1	2
Age of head of household	2	2	3	1.095238	0	5
Education of head of household	0	0	0	.4647592	0	2
Number of household members	3	5	8	3.888566	1	53
Number of children 5 and under (de jure)	0	1	2	1.244858	0	13
Pregnancy status from Individual file	0	0	0	.3253848	0	1
Wealth index	2	3	4	1.430926	1	5
Has television	0	0	0	.3642138	0	1
Has radio	0	1	1	.4758061	0	1
Has telephone (land-line)	0	0	0	.1526962	0	1
Frequency of reading newspaper or magazine	0	0	0	.5041002	0	3
Frequency of listening to radio	0	1	2	.9870999	0	3
Frequency of watching television	0	0	1	.8740024	0	3
Person who usually decides on respondent's health care	4	4	4	1.208403	1	6
Visited health facility last 12 months	0	0	1	.4956499	0	1
Getting medical help for self: distance to health facility	1	2	2	.4984484	1	2

Descriptive statistics for the independent variables for the household (HR) recode.

Household member (PR) recode

	p25	p50	p75	sd	min	max
Use of bednet	0	0	1	.4555768	0	1
Region	4	7	10	3.569188	1	13
Type of place of residence	0	0	0	.4137545	0	1
Age	0	0	2	1.199087	0	5
Sex of household member	1	2	2	.4973159	1	2
Religion	1	2	3	1.101079	0	4
Ethnicity	6	7	7	20.11393	1	98
Sex of head of household	1	1	1	.3107145	1	2
Age of head of household	2	3	3	.9002045	1	5
Education of head of household	0	0	0	.3633539	0	2
Number of household members	7	10	13	5.534423	1	53
Number of mosquito bed nets	0	1	3	1.833752	0	10
Age of bednet	1	3	5	1.523559	1	5
Relationship to head	2	3	3	1.711907	0	12
Wealth index	2	3	4	1.363427	1	5
Has television	0	0	0	.3584271	0	1
Has radio	0	1	1	.4495222	0	1
Visited health facility last 12 months	0	0	1	.4945198	0	1
Getting medical help for self: distance to health facility	1	2	2	.4991992	1	2

Descriptive statistics for the independent variables for the household member (PR) recode.

Appendix

Women (IR) recode

	p25	p50	p75	sd	min	max
Region	4	7	10	3.811724	1	14
Type of place of residence	0	0	1	.4422832	0	1
Age in 5-year groups	2	3	5	1.904074	1	7
Religion	1	1	3	1.052275	0	4
Ethnicity	6	7	7	23.07599	1	98
Currently pregnant	0	0	0	.296882	0	1
Sex of household head	1	1	1	.2855094	1	2
Age of head of household	2	2	3	.9814779	0	5
Number of household members (listed)	5	7	11	5.146947	1	53
Relationship to household head	2	2	2	1.821763	0	12
Number of mosquito bed nets	0	1	3	1.7111	0	10
Age of bednet	2	2	3	1.373906	1	5
Education of head of household	0	0	0	.4589488	0	2
Number of wives	0	0	1	.8450853	0	3
Number of dead children	0	0	1	1.098046	0	12
Wealth index	2	3	4	1.410197	1	5
Education	0	0	1	.4512793	0	2
Education of partner	0	0	0	.4226542	0	2
Literacy	0	0	0	.7541231	0	2
working	1	1	1	.3712808	0	1
Household has: telephone (land-line)	0	0	0	.1838569	0	1
Frequency of reading newspaper or magazine	0	0	0	.5010179	0	3
Frequency of listening to radio	0	1	2	.9925612	0	3
Antenatal visit	1	1	1	.3303499	0	1
Visited health facility last 12 months	0	0	1	.4996305	0	1
Person who usually decides on respondent's health care	4	4	4	1.123652	1	6
Person who usually decides on large household purchases	4	4	4	1.076085	1	6

Descriptive statistics for the independent variables for the women (IR) recode.

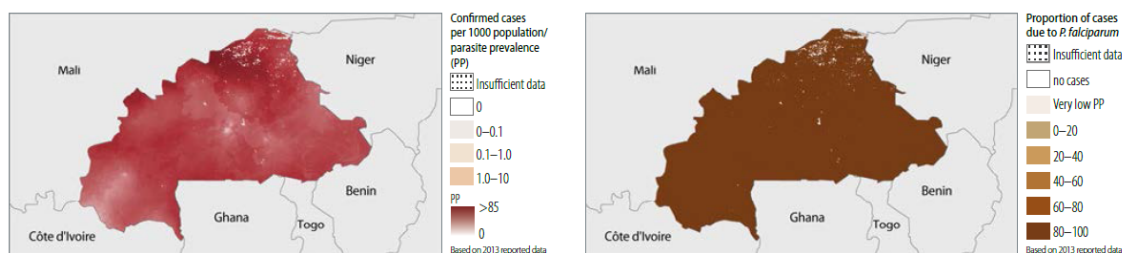
Appendix

Children (KR) recode

	p25	p50	p75	sd	min	max
Region	4	7	10	3.646571	1	13
Type of place of residence	0	0	0	.389597	0	1
Age in 5-year groups	2	3	4	1.428385	1	7
Religion	1	1	3	1.074367	0	4
Sex of household head	1	1	1	.2334876	1	2
Age of head of household	2	2	3	.9207584	1	5
Number of household members (listed)	5	7	11	4.958915	2	53
Number of mosquito bed nets	0	1	3	1.633447	0	10
Relationship to household head	2	2	2	1.162099	0	12
Education of head of household	0	0	0	.4010419	0	2
Wealth index	2	3	4	1.337924	1	5
Education	0	0	0	.3782655	0	2
Partner education	0	0	0	.390422	0	2
Working	1	1	1	.3343926	0	1
Number of wives	0	0	1	.8157581	0	3
Number of dead children	0	0	1	1.01667	0	12
Frequency of listening to radio	0	1	2	.9803549	0	3
Frequency of watching television	0	0	0	.7856869	0	3
Visited health facility last 12 months	0	1	1	.4816643	0	1
Getting medical help for self: distance to health facility	1	2	2	.4990899	1	2
Person who usually decides on respondent's health care	4	4	4	1.01244	1	6
Person who usually decides on large household purchases	4	4	4	.9786387	1	6
Ever had vaccination	1	1	1	.3972701	0	1

Descriptive statistics for the independent variables for the children (KR) recode.

12.10 WHO - World Malaria Report 2015 - Burkina Faso Country Profile



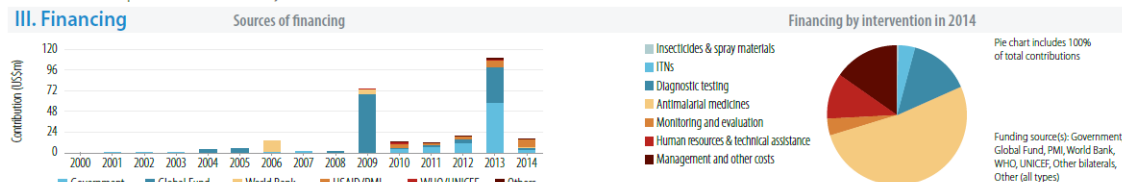
I. Epidemiological profile

Population	2014	%	Parasites and vectors
High transmission (>1 case per 1000 population)	17 600 000	100	Major plasmodium species: <i>P. falciparum</i> (100%), <i>P. vivax</i> (0%)
Low transmission (0–1 cases per 1000 population)	0	0	Major anopheles species: <i>An. gambiae</i> , <i>An. funestus</i> , <i>An. arabiensis</i>
Malaria free (0 cases)	0	0	Programme phase: Control
Total	17 600 000		Reported confirmed cases: 5 428 655 Estimated cases, 2013: [4 700 000–10 000 000]
			Reported deaths: 5632 Estimated deaths, 2013: [12 000–32 000]

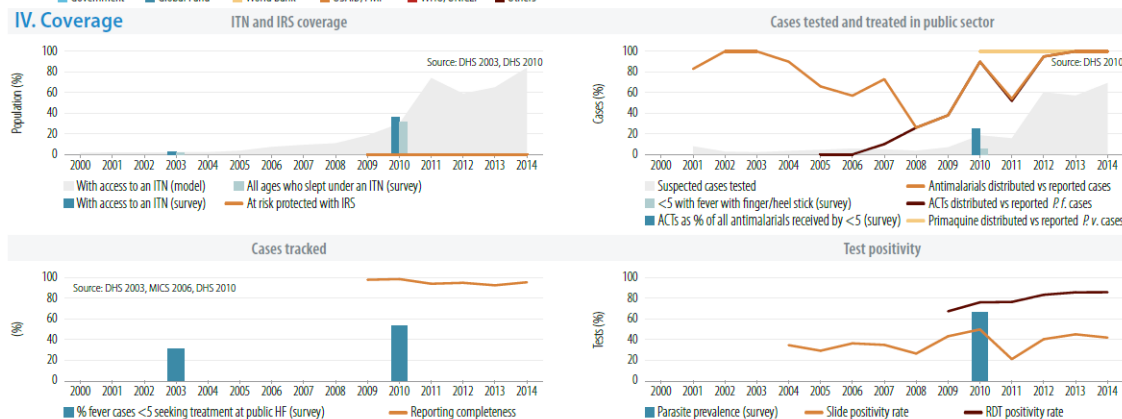
II. Intervention policies and strategies

Intervention	Policies/strategies	Yes/No	Adopted	Antimalaria treatment policy	Medicine	Adopted					
ITN	ITNs/LLINs distributed free of charge	Yes	2007	First-line treatment of unconfirmed malaria	AL; AS+AQ	2005					
	ITNs/LLINs distributed to all age groups	Yes	1998	First-line treatment of <i>P. falciparum</i>	AL; AS+AQ	2005					
IRS	IRS is recommended	Yes	2006	Treatment failure of <i>P. falciparum</i>	QN	–					
	DDT is authorized for IRS	No	–	Treatment of severe malaria	AS; QN	–					
Larval control	Use of larval control recommended	Yes	2012	Treatment of <i>P. vivax</i>	–	–					
IPT	IPT used to prevent malaria during pregnancy	Yes	2005	Dosage of primaquine for radical treatment of <i>P. vivax</i>	–	–					
Diagnosis	Patients of all ages should receive diagnostic test	Yes	2009	Type of RDT used		<i>P. f.</i> only.					
	Malaria diagnosis is free of charge in the public sector	Yes	2009	Therapeutic efficacy tests (clinical and parasitological failure, %)							
Treatment	ACT is free for all ages in public sector	No	–	Medicine	Year	Min	Median	Max	Follow-up	No. of studies	Species
	Sale of oral artemisinin-based monotherapies	Never allowed	–	AL	2005–2012	0	6.15	12.5	28 days	9	<i>P. falciparum</i>
	Single dose of primaquine is used as gametocidal medicine for <i>P. falciparum</i>	No	–	AS+AQ	2006–2012	0	5.05	21.5	28 days	6	<i>P. falciparum</i>
	Primaquine is used for radical treatment of <i>P. vivax</i>	No	–								
	G6PD test is a requirement before treatment with primaquine	No	–								
	Directly observed treatment with primaquine is undertaken	No	–								
	System for monitoring of adverse reactions to antimalarials exists	Yes	2009	Insecticide susceptibility bioassays (reported resistance to at least one insecticide for any vector at any locality)							
Surveillance	ACD for case investigation (reactive)	No	–	Year	Pyrethroid	DDT	Carbamate	Organophosphate	Species/complex tested		
	ACD of febrile cases at community level (pro-active)	No	–	2010–2014	Yes	Yes	Yes	Yes	<i>An. arabiensis</i> , <i>An. coluzzii</i> , <i>An. gambiae</i> s.l.		
	Mass screening is undertaken	No	–								
	Uncomplicated <i>P. falciparum</i> cases routinely admitted	Yes	–								
	Uncomplicated <i>P. vivax</i> cases routinely admitted	No	–								

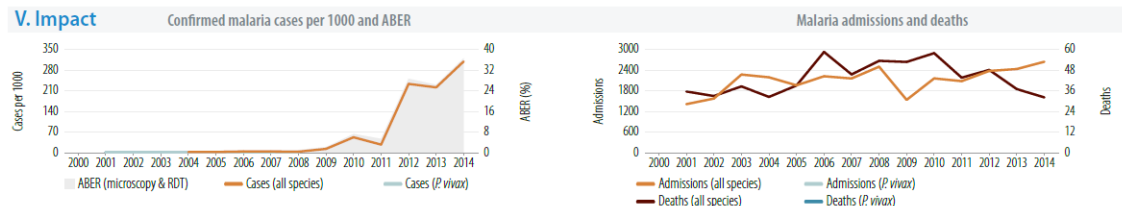
III. Financing



IV. Coverage

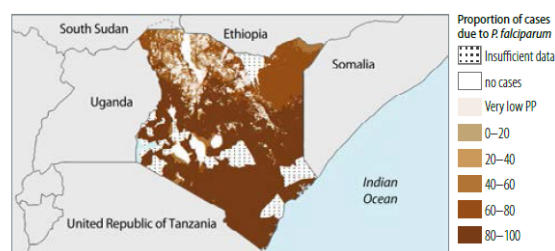
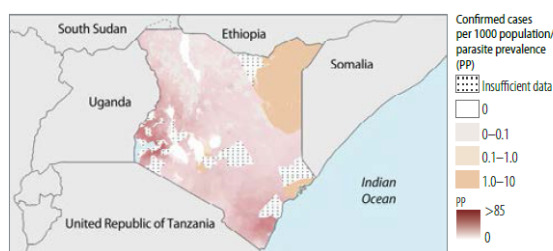


V. Impact



Impact: Insufficiently consistent data to assess trends

12.11 WHO - World Malaria Report 2015 – Kenya Country Profile



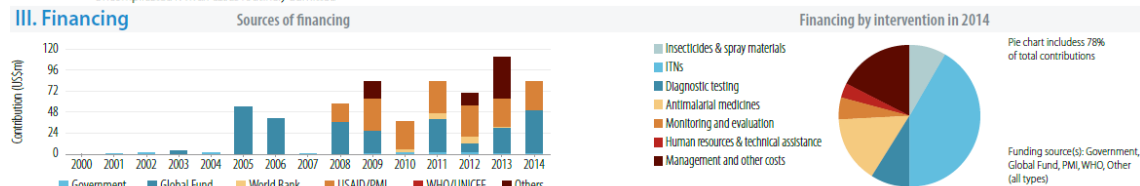
I. Epidemiological profile

Population	2014	%	Parasites and vectors
High transmission (>1 case per 1000 population)	31 500 000	70	Major plasmodium species: <i>P. falciparum</i> (100%), <i>P. vivax</i> (0%)
Low transmission (0-1 cases per 1000 population)	13 400 000	30	Major anopheles species: <i>An. gambiae</i> , <i>An. arabiensis</i> , <i>An. funestus</i> , <i>An. merus</i>
Malaria free (0 cases)	0	0	Programme phase: Control
Total	44 900 000		Reported confirmed cases: 2 808 931 Estimated cases, 2013: [3 800 000-11 000 000]
			Reported deaths: 472 Estimated deaths, 2013: [2500-12 000]

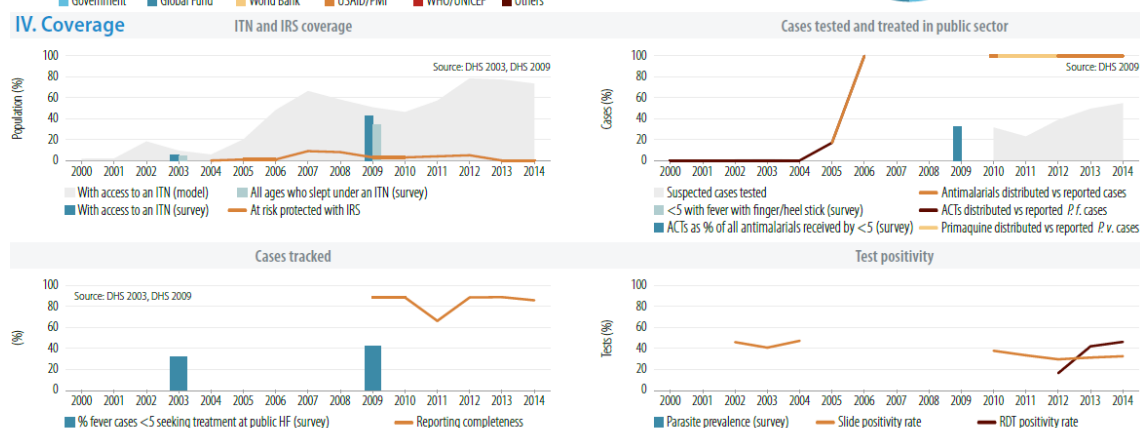
II. Intervention policies and strategies

Intervention	Policies/strategies	Yes/No	Adopted	Antimalaria treatment policy	Medicine	Adopted
ITN	ITNs/LINs distributed free of charge	Yes	2006	First-line treatment of unconfirmed malaria	AL	2004
	ITNs/LINs distributed to all age groups	Yes	2010	First-line treatment of <i>P. falciparum</i>	AL	2004
IRS	IRS is recommended	Yes	2003	Treatment failure of <i>P. falciparum</i>	QN	2004
	DDT is authorized for IRS	No	—	Treatment of severe malaria	AS; AM; QN	2004
Larval control	Use of larval control recommended	No	—	Treatment of <i>P. vivax</i>	—	—
	IPT used to prevent malaria during pregnancy	Yes	2001	Dosage of primaquine for radical treatment of <i>P. vivax</i>	—	—
Diagnosis	Patients of all ages should receive diagnostic test	Yes	2009	Type of RDT used	<i>P. f.</i> only	—
	Malaria diagnosis is free of charge in the public sector	Yes	—			
Treatment	ACT is free for all ages in public sector	Yes	2006	Therapeutic efficacy tests (clinical and parasitological failure, %)		
	Sale of oral artemisinin-based monotherapies	Is banned	—	Medicine	Year	Min
	Single dose of primaquine is used as gametocidal medicine for <i>P. falciparum</i>	No	—		2005-2011	0
	Primaquine is used for radical treatment of <i>P. vivax</i>	—	—			1.65
	G6PD test is a requirement before treatment with primaquine	—	—			6.6
	Directly observed treatment with primaquine is undertaken	—	—			28 days
	System for monitoring of adverse reactions to antimalarials exists	Yes	—			16
Surveillance	ACD for case investigation (reactive)	No	—			
	ACD of febrile cases at community level (pro-active)	No	—			
	Mass screening is undertaken	No	—			
	Uncomplicated <i>P. falciparum</i> cases routinely admitted	No	—			
	Uncomplicated <i>P. vivax</i> cases routinely admitted	—	—			

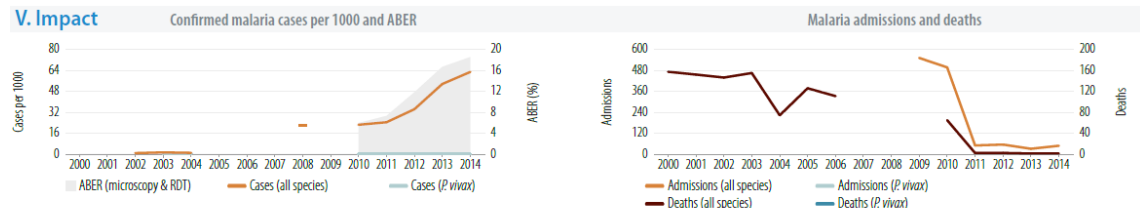
III. Financing



IV. Coverage



V. Impact



Impact: Insufficiently consistent data to assess trends